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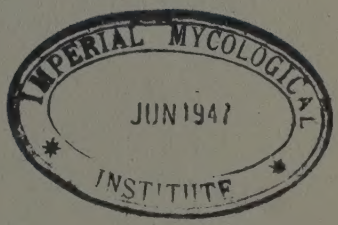

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MATHÉMATIQUES

SUR LES SOLUTIONS PÉRIODIQUES DES ÉQUATIONS DIFFÉRENTIELLES NON-LINÉAIRES DE TYPE PARABOLIQUE

Par Dj. KARIMOFF

(Présenté par S. L. Soboleff, de l'Académie, le 6.XI.1944)

La présente Note est le développement des travaux (1), où l'on a considéré les équations

$$\frac{\partial Z}{\partial t} - a^2 \frac{\partial^2 Z}{\partial x^2} = \Phi(x, t) + \mu f(Z)$$

$$\frac{\partial}{\partial x}\left[P(x)\frac{\partial Z}{\partial x}\right] - \frac{\partial Z}{\partial t} = \Phi(x, t) + \mu f(Z)$$

en exigeant que

$$Z(0, t) = Z(\pi, t) = 0, \qquad Z(x, t) = Z(x, t+1)$$

et démontré, en imposant certaines restrictions à μ, $\Phi(x, t)$ et $f(Z)$, l'existence et l'unicité de la solution.

Nous considérons ici une équation plus générale

$$\frac{\partial}{\partial x}\left[P(x)\frac{\partial Z}{\partial x}\right] - \frac{\partial Z}{\partial t} = \Phi(x, t) + \mu f\left(Z, \frac{\partial Z}{\partial t}\right) \tag{1}$$

dans le domaine

$$\overline{D} = D\begin{pmatrix} 0 \leqslant x \leqslant \pi \\ 0 \leqslant t \leqslant 1 \end{pmatrix}.$$

et nous cherchons la solution de l'équation (1) vérifiant les conditions

$$Z(0, t) = Z(\pi, t) = 0, \qquad Z(x, t) = Z(x, t+1) \tag{2}$$

Soit $P(x)$ une fonction continue ainsi que ses dérivées $P'(x)$, $P''(x)$ dans le domaine $\overline{D}$, et soit $P(x) \geqslant k > 0$, $P'(x) \not\equiv 0$.

La fonction $\Phi(x, t)$ est continue, ainsi que sa dérivée $\Phi_1(x, t) = \partial\Phi/\partial x$, dans le domaine $\overline{D}$ et périodique de période 1 par rapport à t: $\Phi(x, t) = \Phi(x, t+1)$; d'ailleurs, elle peut être développée en une série absolument et uniformément convergente suivant les fonctions du système orthogonal et normal $\{\chi_n(x)\}$

$$\Phi(x, t) = \sum_{n=0}^{\infty} \Phi_n(t)\,\chi_n(x)$$

où

$$\Phi_n(t) = \int_0^{\pi} \Phi(\eta, t)\,\chi_n(\eta)\,d\eta$$

Les fonctions $\chi_1(x)$, $\chi_2(x)$, ... $\chi_n(x)$, ... sont les fonctions caractéristiques de l'équation de Sturm-Liouville

$$\frac{d}{dx}\left[P(x)\frac{d\chi_n}{dx}\right]+\lambda_n\chi_n(x)=0$$

assujetties aux conditions limites $\chi_n(0)=\chi_n(\pi)=0$; et les λ_n sont les nombres caractéristiques correspondants. Les conditions imposées à $\Phi(x,t)$ seront nommées dans la suite «conditions A».

Théorème. *L'équation différentielle* (1) *admet une solution unique continue avec ses dérivées partielles jusqu'au second ordre* dans le domaine D vérifiant les conditions* (2) *et périodique de période* 1 *par rapport à t si l'on a:*

1) *la fonction* $\Phi(x,t)$ *vérifie les conditions* A;

2) $$\left|f'\left(Z_1,\frac{\partial Z_1}{\partial x}\right)-f'\left(Z_2,\frac{\partial Z_2}{\partial x}\right)\right|<M_1|Z_1-Z_2|+M_2\left|\frac{\partial Z_1}{\partial x}-\frac{\partial Z_2}{\partial x}\right|\ ;\quad f_{\substack{x=0\\x=\pi}}=0;$$

3) *la valeur absolue de* μ *est assez petite.*

Nous allons résoudre ce problème par la méthode des approximations successives de Picard. Prenons pour approximation initiale $Z_0(x,t)$ la solution de l'équation

$$\frac{\partial}{\partial x}\left[P(x)\frac{\partial Z_0}{\partial x}\right]-\frac{\partial Z_0}{\partial t}=\Phi(x,t) \tag{3}$$

vérifiant les conditions (2).

La solution de cette équation est de la forme

$$Z_0(x,t)=\sum_{n=0}^{\infty}T_n^{(0)}(t)\chi_n(x) \tag{4}$$

où

$$T_n^{(0)}(t)=\int_0^1\frac{e^{\lambda_n(\xi-Z)}\,d\xi}{1-e^{\lambda_n}}\int_0^{\pi}\Phi(\eta,\xi)\chi_n(\eta)\,d\eta-\int_0^t e^{\lambda_n(\xi-Z)}\,d\xi\int_0^{\pi}\Phi(\eta,\xi)\chi_n(\eta)\,d\eta$$

Il est facile à voir que $Z_0(x,t)$ vérifie les équations (2) et présente une fonction continue ainsi que ses dérivées partielles jusqu'au second ordre dans le domaine $\overline{D}$, et périodique de période 1 par rapport à t.

Si la $(k-1)$-ième approximation $Z_{k-1}(x,t)$ est connue, on cherche la k-ième approximation $Z_k(x,t)$ comme solution de l'équation

$$\frac{\partial}{\partial x}\left[P(x)\frac{\partial Z_k}{\partial x}\right]-\frac{\partial Z_k}{\partial t}=\Phi(x,t)+\mu f\left(Z_{k-1},\frac{\partial Z_{k-1}}{\partial x}\right) \tag{5}$$

dans les conditions (2).

Cette approximation sera de la forme

$$Z_k(x,t)=\sum_{n=0}^{\infty}T_n^{(k)}(t)\chi_n(x) \tag{6}$$

où

$$T_n^{(k)}(t)=\int_0^1\frac{e^{\lambda_n(\xi-Z)}\,d\xi}{1-e^{\lambda_n}}\int_0^{\pi}\left[\Phi(\eta,\xi)+\mu f\left(Z_{k-1},\frac{\partial Z_{k-1}}{\partial x}\right)\right]\chi_n(\eta)\,d\eta-$$

$$-\int_0^t e^{\lambda_n(\xi-t)}\,d\xi\int_0^{\pi}\left[\Phi(\eta,\xi)+\mu f\left(Z_{k-1},\frac{\partial Z_{k-1}}{\partial x}\right)\right]\chi_n\,d\eta$$

* A savoir: la dérivée première par rapport à t et les dérivées première et seconde par rapport à x.

et d'ailleurs $Z_k(x, t)$ est une fonction continue ainsi que ses dérivées $\partial Z_k/\partial t$; $\partial Z_k/\partial x$; $\partial^2 Z_k/\partial x^2$ dans le domaine $\overline{D}$, périodique par rapport à t de période 1 et vérifiant les conditions (2).

La limite $Z_k(x, t)$, $k \to \infty$,

$$\lim_{k\to\infty} Z_k(x, t) = Z(x, t)$$

existe et donne la solution du problème posé.

Pour démontrer cette proposition il suffit de considérer la série

$$Z_0 + (Z_1 - Z_0) + \ldots + (Z_k - Z_{k-1}) + \ldots \tag{7}$$

La série (7) converge absolument et uniformément dans le domaine $\overline{D}$. En effet

$$|Z_k - Z_{k-1}| \leqslant$$

$$\leqslant |\mu| \sum_{n=0}^{\infty} |\chi_n(x)| \left| \int_0^1 \frac{e^{\lambda_n(\xi-t)}\,d\xi}{1-e^{\lambda_n}} \int_0^{\pi} \left[f\left(Z_{k-1}, \frac{\partial Z_{k-1}}{\partial x}\right) - f\left(Z_{k-2}, \frac{\partial Z_{k-2}}{\partial x}\right) \right] \chi_n(\eta)\,d\eta - \right.$$

$$\left. - \int_0^t e^{\lambda_n(\xi-t)}\,d\xi \int_0^{\pi} \left[f\left(Z_{k-1}, \frac{\partial Z_{k-1}}{\partial x}\right) - f\left(Z_{k-2}, \frac{\partial Z_{k-2}}{\partial x}\right) \right] \chi_n(\eta)\,d\eta \right| \leqslant$$

$$\leqslant B^2 N\pi \left[\sup |Z_{k-1} - Z_{k-2}| + \sup \left| \frac{\partial Z_{k-1}}{\partial x} - \frac{\partial Z_{k-2}}{\partial x} \right| \right] \left[\sum_{n=0}^{n_0} \frac{|1-2e^{-\lambda_n t}|}{|\lambda_n|} + \sum_{n=n_0}^{\infty} \frac{1}{\lambda_n} \right]$$

ou bien

$$|Z_k - Z_{k-1}| \leqslant Q \left[\sup |Z_{k-1} - Z_{k-2}| + \sup \left| \frac{\partial Z_{k-1}}{\partial x} - \frac{\partial Z_{k-2}}{\partial x} \right| \right] \tag{8}$$

où

$$Q = B^2 N\pi |\mu| C; \quad N = \sup \left\{ \frac{\partial f}{\partial Z_{k-1}}, \frac{\partial f}{\partial Z_{k-2}} \right\}; \quad C = \sum_{n=0}^{n_0} \frac{|1-2e^{-\lambda_n t}|}{|\lambda_n|} + \sum_{n=n_0}^{\infty} \frac{1}{\lambda_n}$$

On démontre de même que

$$\left| \frac{\partial Z_k}{\partial x} - \frac{\partial Z_{k-1}}{\partial x} \right| \leqslant Q_1 \left[\sup |Z_{k-1} - Z_{k-2}| + \sup \left| \frac{\partial Z_{k-1}}{\partial x} - \frac{\partial Z_{k-2}}{\partial x} \right| \right] \tag{9}$$

où

$$Q_1 = B^2 N\pi |\mu| C_1; \quad C_1 = \sum_{n=0}^{n_0} \frac{|1-2e^{-\lambda_n t}|}{\sqrt{|\lambda_n|}} + \sum_{n=n_0}^{\infty} \frac{1}{\sqrt{\lambda_n}}$$

En posant dans les inégalités (8) et (9) $k = 2, 3, \ldots$, on obtient

$$|Z_2 - Z_1| \leqslant Q \left[\sup |Z_1 - Z_0| + \sup \left| \frac{\partial Z_1}{\partial x} - \frac{\partial Z_0}{\partial x} \right| \right]$$

$$|Z_3 - Z_2| \leqslant Q(Q + Q_1) \left[\sup |Z_1 - Z_0| + \sup \left| \frac{\partial Z_1}{\partial x} - \frac{\partial Z_0}{\partial x} \right| \right]$$

. . . . . .

$$|Z_k - Z_{k-1}| \leqslant Q(Q + Q_1)^{k-2} \left[\sup |Z_1 - Z_0| + \sup \left| \frac{\partial Z_1}{\partial x} - \frac{\partial Z_0}{\partial x} \right| \right]$$

. . . . . .

Ainsi la série numérique $|Z_0| + |Z_1 - Z_0| + \sum_{k=0}^{\infty} Q(Q + Q_1)^k L$ est une majorante par rapport à la série (7) et pour les valeurs assez petites de μ elle converge, donc la série (7) converge absolument et uniformément dans le domaine $\overline{D}$.

Cela étant, on peut écrire

$$Z(x,t)=\sum_{n=0}^{\infty}\chi_n(x)\int_0^1\frac{e^{\lambda_n(\xi-t)}\,d\xi}{1-e^{\lambda_n}}\int_0^{\pi}\left[\Phi(\eta,\xi)+\mu f\left(Z,\frac{\partial Z}{\partial x}\right)\right]\chi_n(\eta)\,d\eta-$$
$$-\sum_{n=0}^{\infty}\chi_n(x)\int_0^t e^{\lambda_n(\xi-t)}\,d\xi\int_0^{\pi}\left[\Phi(\eta,\xi)+\mu f\left(Z,\frac{\partial Z}{\partial x}\right)\right]\chi_n(\eta)\,d\eta.$$

Ensuite, il est facile à voir que les séries

$$\frac{\partial Z}{\partial t}=\sum_{k=0}^{\infty}\left[\frac{\partial Z_k}{\partial t}-\frac{\partial Z_{k-1}}{\partial t}\right]$$
$$\frac{\partial Z}{\partial x}=\sum_{k=0}^{\infty}\left[\frac{\partial Z_k}{\partial x}-\frac{\partial Z_{k-1}}{\partial x}\right]$$
$$\frac{\partial^2 Z}{\partial x^2}=\sum_{k=0}^{\infty}\left[\frac{\partial^2 Z_k}{\partial x^2}-\frac{\partial^2 Z_{k-2}}{\partial x^2}\right]\qquad(Z_{-1}\equiv 0)$$

convergent aussi absolument et uniformément dans le domaine $\overline{D}$.

Il reste à montrer que la solution trouvée $Z(x,t)$ est unique. Supposons qu'il existe deux solutions continues $Z(x,t)$ et $V(x,t)$ de l'équation (1) et qu'elles vérifient les équations (2); alors la différence $Z-V=K$ est une solution de l'équation différentielle

$$\frac{\partial}{\partial x}\left[P(x)\frac{\partial K}{\partial x}\right]-\frac{\partial K}{\partial t}=\mu\left[f\left(Z,\frac{\partial Z}{\partial x}\right)-f\left(V,\frac{\partial V}{\partial x}\right)\right]$$

et de même la solution de l'équation intégrale

$$K(x,t)=\mu\sum_{n=0}^{\infty}\chi_n(x)\left[\int_0^1\frac{e^{\lambda_n(\xi-t)}\,d\xi}{1-e^{\lambda_n}}\int_0^{\pi}\left[f\left(Z,\frac{\partial Z}{\partial x}\right)-f\left(V,\frac{\partial V}{\partial x}\right)\right]\chi_n(\eta)\,d\eta-\right.$$
$$\left.-\int_0^t e^{\lambda_n(\xi-t)}\,d\xi\int_0^{\pi}\left[f\left(Z,\frac{\partial Z}{\partial x}\right)-f\left(V,\frac{\partial V}{\partial x}\right)\right]\chi_n(\eta)\,d\eta\right]$$

En évaluant le module de $K(x,t)$ on obtient:

$$|Z-V|\leqslant B^2N\pi|\mu|C\left[\sup|Z-V|+\sup\left|\frac{\partial Z}{\partial x}-\frac{\partial V}{\partial x}\right|\right]$$
$$\left|\frac{\partial Z}{\partial x}-\frac{\partial V}{\partial x}\right|\leqslant B^2N\pi|\mu|C_1\left[\sup|Z-V|+\sup\left|\frac{\partial Z}{\partial x}-\frac{\partial V}{\partial x}\right|\right]$$

ou bien

$$\sup Z-V|+\sup\left|\frac{\partial Z}{\partial x}-\frac{\partial V}{\partial x}\right|\leqslant|\mu\ B^2N\pi(C+C_1)\left[\sup|Z-V|+\sup\left|\frac{\partial Z}{\partial x}-\frac{\partial V}{\partial x}\right|\right]$$

ce qui est impossible pour $|\mu|<1:B^2N\pi(C+C_1)$. Donc, $Z(x,t)\equiv V(x,t)$, et le théorème est ainsi démontré.

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[1] Dj. Karimoff, C. R. Acad. Sci. URSS, XXV, No. 1 (1939); XXVIII, No. 5 (1940)

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MECHANICS

INTEGRAL INVARIANTS OF THE EQUATIONS OF ANALYTICAL DYNAMICS IN NON-HOLONOMIC COORDINATES

By V. V. DOBRONRAVOV

(Communicated by N. E. Kochin, Member of the Academy, 18.V.1944)

Consider a tube formed by trajectories every one of which passes through some point of a closed linear contour in the space of states $\{\pi_i, \mathfrak{P}_i, t\}$* of the system (1). Consider also the principal Hamilton function $S = \int_{t_1}^{t_2} L\,dt$ («action») as a function of two arbitrary points (6) $A_1(t_1)$ and $A_2(t_2)$ of a trajectory. We take the complete variation δS for the transition to arbitrary points of a neighbouring trajectory in an arbitrary direction: $\delta S = L_2\,\delta t_2 - L_1\,\delta t_1 + \int_{t_1}^{t_2} \Delta L\,dt$, where ΔL denotes the isochronal variation. By using the equations of motion in non-holonomic coordinates and the transitivity equation

$$\delta\,d\pi_r - d\,\delta\pi_r = \sum_{\sigma}\sum_{\tau} \gamma^r_{\sigma\tau}\,d\pi_\sigma\,\delta\pi_\tau \qquad (1)$$

we put ΔL in an explicit form. Then we integrate δS round the tube and obtain the first (relative) integral invariant** in non-holonomic coordinates:

$$I_1 \equiv \oint \Big(\sum_{\tau=1}^{n} \mathfrak{P}_\tau\,\delta\pi_\tau - H\,\delta t \Big) = \text{const} \qquad (2)$$

Conversely, if the integral invariant I_1 exists for a system of differential equations in such variables for which the transitivity equation is of the form (1), the system of equations considered has necessarily the form (generalization of Lie—Königs' theorem):

$$\frac{d\pi_i}{dt} = \frac{\partial H}{\partial \mathfrak{P}_i}, \qquad \frac{d\mathfrak{P}_i}{dt} = -\frac{\partial H}{\partial \pi_i} + \sum_{\sigma}\sum_{\tau} \gamma^\sigma_{\tau i}\,\mathfrak{P}_\sigma \frac{\partial H}{\partial \mathfrak{P}_\tau} \qquad (3)$$

Integral invariants for the given system in non-holonomic coordinates of higher orders admitted by the number of degrees of freedom are the (absolute) invariants (7) of the following structure:

$$I_2 \equiv \iint \Omega'; \quad I_{2k} \equiv \underbrace{\iint \ldots \int}_{2k} [\Omega']^k \qquad (4)$$

where Ω denotes the form under the integral sign in I_1.

Explicitly we shall, *e. g.*, have the invariants of the following form:

$$I_2 \equiv \iint \Big\{ \sum_i \Big[\delta\mathfrak{P}_i\,\delta\pi_i + \sum_\rho \sum_r{}' \gamma^i_{\rho r}\,\mathfrak{P}_i\,\delta\pi_\rho\,\delta\pi_r \Big] - \delta H\,\delta t \Big\} = \text{const} \qquad (5)$$

---

* $\mathfrak{P}_i$ are the quasi-impulses.

** The integral invariant of the first order in the Poincaré—Lie variables, *i. e.* for the case $\gamma^r_{\sigma\tau} = \text{const}$ and for holonomic systems, was first obtained by Chetajew (2) by a different method from the Poincaré equations (5).

(the touch indicates summation over combinations of indices). Analogously

$$I_4 \equiv \int\int\int\int \Big\{ \sum_{\rho,\lambda}{}' \delta\mathfrak{P}_\rho\, \delta\pi_\rho\, \delta\mathfrak{P}_\lambda\, \delta\pi_\lambda + \sum_{\lambda,\mu,\nu}{}' \gamma^i_{\nu\mu}\mathfrak{P}_i\, \delta\mathfrak{P}_\lambda\, \delta\pi_\lambda\, \delta\pi_\mu\, \delta\pi_\nu + \\ + \sum_i \sum_j \sum_{\lambda,\mu,\nu,h}{}' \gamma^i_{\lambda\mu}\gamma^j_{\nu h}\mathfrak{P}_i\mathfrak{P}_j\, \delta\pi_\lambda\, \delta\pi_\mu\, \delta\pi_\nu\, \delta\pi_h - \\ - \sum_i \Big[\delta\mathfrak{P}_i\, \delta\pi_i\, \delta H\, \delta t - \sum_{\sigma,\tau}{}' \gamma^i_{\sigma\tau}\mathfrak{P}^i\, \delta\pi_\sigma\, \delta\pi_\tau\, \delta H\, \delta t \Big] \Big\} = \text{const } etc. \tag{6}$$

Finally, we shall have the integral invariant of the highest order in the phase space $\{\pi_i, \mathfrak{P}_i\}$ for any moment of time:

$$I_{2n} \equiv \underbrace{\int\int \dots \int}_{2n} \delta\mathfrak{P}_1\, \delta\pi_1\, \delta\mathfrak{P}_2\, \delta\pi_2 \dots \delta\mathfrak{P}_n\, \delta\pi_n = \text{const} \tag{7}$$

The integral invariants in non-holonomic coordinates take place also for mechanical systems with non-holonomic constraints, because the constraint-equations can be put in the form $\delta\pi_i = 0$ $(i = 1, 2, \dots, m)$ [3] so that the calculations necessary for obtaining the first and accordingly all the other invariants remain valid. The highest invariant in this case is naturally of order $< 2n$. Poincaré's and Cartan's invariants can be derived without any difficulty from the above invariants, all the components γ^i_{jk} of the Schouten object of non-holonomicity being zero in any holonomic system of references. Poisson's and Laurent's theorems in non-holonomic coordinates follow immediately from the existence of integral invariants (the former has been proved by the author irrespective of the integral invariants). Thus, *e. g.*, given four first integrals $F_1 = C_1$, $F_2 = C_2$, $F_3 = C_3$, $F_4 = C_4$ for the equations (3), the equality

$$\sum_{\rho,\sigma}{}' \frac{D(F_1, F_2, F_3, F_4)}{D(\mathfrak{P}_\rho, \pi_\rho, \mathfrak{P}_\sigma, \pi_\sigma)} + \sum_t \sum_{\lambda,\mu,\nu}{}' \gamma^i_{\mu\nu}\mathfrak{P}_i \frac{D(F_1, F_2, F_3, F_4)}{D(\mathfrak{P}_\lambda, \pi_\lambda, \pi_\mu, \pi_\nu)} + \\ + \sum_i \sum_j \sum_{\lambda,\mu,\nu;h}{}' \gamma^i_{\lambda\mu}\gamma^j_{\nu h}\mathfrak{P}_i\mathfrak{P}_j \frac{D(F_1, F_2, F_3, F_4)}{D(\pi_\lambda, \pi_\mu, \pi_\nu, \pi_h)} = 0 \tag{8}$$

furnishes, in general, a new integral *etc.* (a generalization of Laurent's theorem).

The invariant I_1 has the same mechanical and geometrical meaning in the space $\{\pi_i, \mathfrak{P}_i, t\}$ as in the space of holonomic coordinates: I_1 is the action corresponding to the movement of the system along a trajectory from one intersection point with a transversal to the next.

From the viewpoint of the calculus of variations, I_1 is the pitch of the spiral run of the transversals on a given tube of trajectories (the transversals are closed only if the form Ω is of the first class).

By replacing all $\delta\pi_i$ by δq_i in I_{2n}, we can put I_{2n} in the form

$$I_{2n} = \underbrace{\int\int \dots \int}_{2n} |\alpha_{ij}|\, \delta\mathfrak{P}_1\, \delta\mathfrak{P}_2 \dots \delta\mathfrak{P}_n\, \delta q_1\, \delta q_2 \dots \delta q_n \tag{9}$$

where $|\alpha_{ij}|$ is the determinant of the matrix which gives the expression of $d\pi_i / dt$ through dq_i / dt. We thus see that $|\alpha_{ij}|$ is Jacobi's last factor for the canonical equation (3) in non-holonomic coordinates, or for the equivalent system of equations

$$\frac{dq_i}{dt} = \sum_{j=1}^{n} \beta_{ji} \frac{\partial H}{\partial \mathfrak{P}_j}, \qquad \frac{d\mathfrak{P}_i}{dt} = -\sum_{j=1}^{n} \frac{\partial H}{\partial q_j}\beta_{ij} + \sum_\sigma \sum_\tau \gamma^\sigma_{\tau i}\mathfrak{P}_\sigma \frac{\partial H}{\partial \mathfrak{P}_\tau} \tag{10}$$

where $\|\beta_{ij}\|$ is the matrix of the transformation inverse to $\|\alpha_{ij}\|$.

As an illustration consider Euler's problem of motion of a solid round a fixed point. The Euler variables p, q, r [4] will be considered as quasi-velocities. We shall have

$$I_1 = \oint [Ap(\sin\varphi\sin\theta\,\delta\psi + \cos\varphi\,\delta\theta) + Bq(\cos\varphi\sin\theta\,\delta\psi - \sin\varphi\,\delta\theta) + Cr(\cos\theta\delta\psi + \delta\varphi) - H\delta t]$$

$$I_2 = \int\int [A(\sin\varphi\sin\theta\,\delta\psi + \cos\varphi\,\delta\theta)\,\delta p + B(\cos\varphi\sin\theta\,\delta\psi - \sin\varphi\,\delta\theta)\,\delta q + C(\cos\theta\,\delta\psi + \delta\varphi)\,\delta r - \delta H\,\delta t] \quad etc.$$

Finally,

$$I_6 = \int\int\int\int\int\int \delta\mathfrak{P}_1\,\delta\mathfrak{P}_2\,\delta\mathfrak{P}_3\,\delta\pi_1\,\delta\pi_2\,\delta\pi_3 = \int\int\int\int\int\int \sin\theta\,\delta p\,\delta q\,\delta r\,\delta\psi\,\delta\theta\,\delta\varphi$$

The last factor for the equations (10) in this case is $\sin\theta$. We can write these equations explicitly and verify that $\sin\theta$ satisfies the partial differential equation for Jacobi's last factor. This example confirms our theory of invariants in non-holonomic coordinates.

The non-holonomic coordinates $\{\pi_i, \mathfrak{P}_i\}$ become necessary, first, for the investigation of mechanical systems with non-holonomic constraints, because the equations of motion both for holonomic and non-holonomic systems have the same structure in these coordinates, which enables us to apply the methods of analytical dynamics to non-holonomic systems (this is not true for the equations in the Lagrange — Hamilton variables $\{q_i, p_i\}$).

Secondly, it is sometimes convenient to introduce non-holonomic parameters for the study of holonomic systems, whereby more symmetric and elegant equations are obtained. One may refer here by way of example to the fundamental problem of the dynamics of a solid, where the quasi-velocities p, q, r were introduced by Euler. In other cases it may be found necessary to change the variables by means of non-integrable linear relations (this sometimes is required in mechanics, as well as in theoretical physics). Then the equations of motion in the new variables will take the same form as in non-holonomic coordinates.

Finally, we may consider the above results from the following point of view. Let us put the question, what does the dynamics look like as the canonical variables $\{q, p\}$ are transformed into new variables $\{Q, P\}$. The answer is known for one class of transformations: as is shown by S. Lie, the fundamental principles of dynamics rest invariant under any contact transformations of canonical variables (namely, the structure of equation remains unaltered). We have just formulated the fundamental principles of analytical dynamics for a case of non-contact transformations of canonical variables, namely, for linear transformations with the step matrix $\| E\beta^*_{ji} \|$, where E is the unit matrix, β^*_{ji} is adjoint to β_{ji}; β_{ji} depends on the first group of initial variables, *i. e.* on q_i and t only.

If we introduce non-holonomic coordinates by means of rheonomic Pfaff's forms $d\pi_\rho = \alpha_{\rho 1}\,dq_1 + \ldots + \alpha_{\rho n}\,dq_n + \alpha_{\rho, n+1}\,dt$, and conversely: $dq_\rho = \beta_{1\rho}\,d\pi_1 + \ldots + \beta_{n\rho}\,d\pi_n + \beta_{n+1,\rho}\,dt$ $(\rho = 1, 2, \ldots, n,\ d\pi_{n+1} = dq_{n+1} = dt)$, then all the above theories remain valid. It is only the Hamilton — Jacobi theory [1] in non-holonomic coordinates, which suffers a slight modification: the canonical equations will have the form:

$$\frac{d\pi_\lambda}{dt} = \frac{\partial H}{\partial \mathfrak{P}_\lambda}; \quad \frac{d\mathfrak{P}_\lambda}{dt} = -\frac{dH}{d\pi_\lambda} + \sum_{s=1}^{n}\sum_{r=1}^{n} \gamma^s_{r\lambda}\mathfrak{P}_s \frac{\partial H}{\partial \mathfrak{P}_r} + \sum_{s=1}^{n} \gamma^s_{n+1,\lambda}\,\mathfrak{P}_s$$

while the Hamilton — Jacobi equation becomes

$$\frac{\partial V}{\partial \pi_{n+1}} + H\left[\frac{\partial V}{\partial \pi_i},\ q_i,\ t\right] = 0 \quad \text{where} \quad \frac{\partial V}{\partial \pi_{n+1}} \equiv \sum_{i=1}^{n+1} \frac{\partial V}{\partial q_i}\beta_{n+1,i}$$

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TECHNICAL PHYSICS

SPECTROPHONE — AN INSTRUMENT FOR INVESTIGATION OF INFRA-RED ABSORPTION SPECTRA OF GASES AND FOR QUANTITATIVE AND QUALITATIVE SPECTRUM ANALYSIS OF MULTI-COMPONENT GAS MIXTURES

By M. L. VEINGEROV

(Communicated by A. A. Lebedev, Member of the Academy, 8.VIII.1944)

Principle of the Method. The usual method for measuring the spectral distribution of light absorption by gases and vapours in the infra-red is to measure successively at different wave-lengths the monochromatic radiation flux through a cell containing the gas and through the same cell when there is no gas in it.

This paper describes a new method by which the energy absorbed by the gas is measured directly. It is based on the effect discovered by Tyndall and Röntgen in 1880, which consists in the emission of sound by gases and vapours when under the action of an intermitted radiation flux. This effect has already been used by the author(1) in optic-acoustical analysis of gases and in constructing an optic-acoustical gas-analyser.

In the new method which has arisen from the development of the optic-acoustical analysis, a monochromatic radiation interrupted by a sound frequency is transmitted through the gas. Whenever absorption takes place in the gas, it is invariably attended by increase in temperature and consequently in pressure. Owing to the intermittent nature of the irradiating beam, the gas pressure rises and falls in quick succession whereby sound vibrations arise in the gas. These vibrations are received by an electrodynamical microphone inserted in the absorption cell. The microphone current is amplified by a high gain amplifier and after rectifying is measured by a pointer galvanometer. The readings of the galvanometer thus depend on the absorption power of the gas for the wave-length given, *i. e.* on the concentration of the absorbing molecules and on the values of the molecular constants that determine the intensity of the corresponding absorption bands. In that way it is possible to record the absorption spectrum. The mixture composition is determined by the position of the absorption bands; the galvanometer pointer shows the concentration of different components.

For the calibration, mixtures of known concentrations and compositions are to be used.

The spectrophone is thus an optic-acoustical gas-analyser adapted for work with monochromatic radiation(2).

The term «spectrophone» was suggested in 1881 by Bell (3) who had given this name to the instrument for investigation of infra-red spectra, based on the optic-acoustical effect. The sound was registered by the ear. Bell expected much from the device.

Yet his expectations could not possibly be materialized at the time for lack

of a sensitive microphone and an amplifier of the sound frequency; his ideas were later forgotten, as the instrument could not be applied for measurements.

Test of the Method. The method described has first been tested on the absorption spectrum of carbon dioxide and then on that of other compounds. The first experiments were run with a cell of the optic-acoustical gas-analyser. The scheme of the method is illustrated by Fig. 1.

The cell consisted of a brass cylinder with an inner diameter of 26 mm. The walls inside the cylinder had been polished and guilded. Owing to this, all of

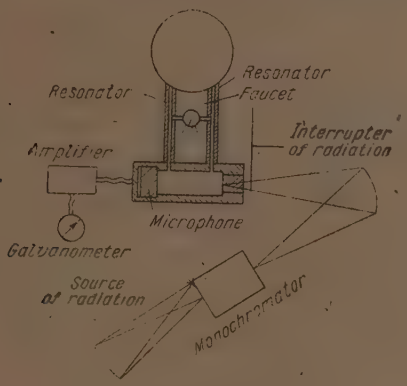

Fig. 1

the radiation falling on them was reflected and let to pass through the gas layer. The length of the cylinder was 75 mm. One of its ends was closed by a thick fluorite window, the other by a membrane of an electrodynamical microphone. In order to reinforce the sound the cell was provided at one side with two resonators which were brass tubes about 10 cm long.

At the frequency used (200 Hertz) these resonators reinforced the sound several times; their lengths had been determined by error and trial. The resonators worked only with their ends open and ceased working at once when their ends were screened. It was not possible, however, to leave them open, on account of external noises. To maintain the resonance and at the same time to protect the microphone from external noises closed glass bulbs were fitted on the ends of the tubes.

The hollows of the bulbs played the rôle of the external space, and their walls to a certain degree protected the cell from external noises. The diameter of the bulbs was about 100 mm. With the bulbs of this size the resonance was as strong as with open tubes.

For improving the acoustic protection the cell was covered by a glass bell, fitted with a window transparent to the radiation. The camera was put on rubber paddings lest the sound should pass into it through the points of contact with the stand.

In some experiments a Nernst glower, in other the crater of a voltaic arc served as a source of radiation. The advantage of the arc is that its brightness is many times greater. The inconstancy of its behaviour is here not so objectionable as with the usual methods of measurement, when the weakening of radiation beams traversing the investigated gas is measured: in the method described the energy directly absorbed by the gas is measured instead of the difference between two beams separated in time.

The monochromator used was designed in the State Optical Institute by J. A. Teltevsky and M. A. Jourieff and will be described by them elsewhere. The relative aperture of the instrument is 1 : 5; the base of the prism, 75 mm. In

some experiments a sylvine prism was used; in others, a prism of rock-salt; and in others again a prism of lithium fluoride (with a 70 mm base).

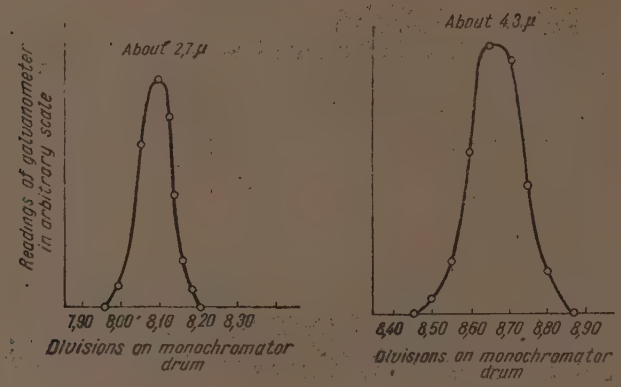

Fig. 2

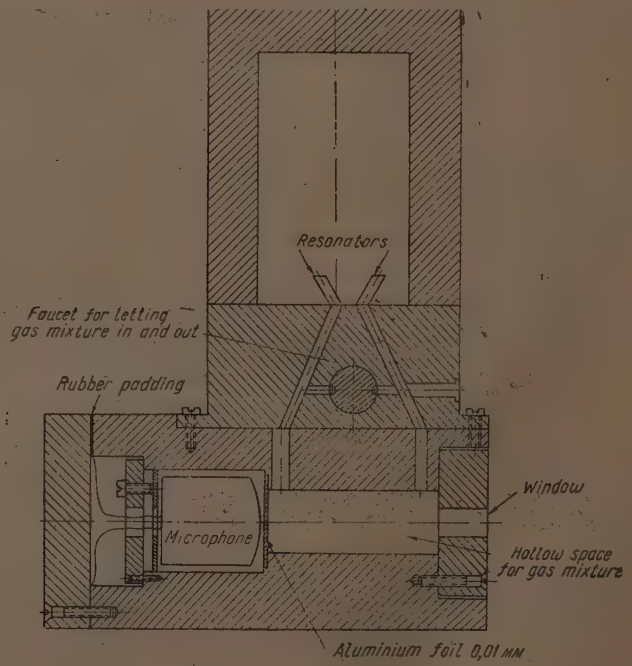

Fig. 3

To amplify the electromotive force given by the microphone in initial experiments a high gain amplifier built by S. A. Cogan was used. At the output of the amplifier a pointer galvanometer has been placed. The spectrophonogram of carbon dioxide, *i. e.* the absorption spectrum, is shown in Fig. 2. The divisions of the monochromator drum are plotted as abscissae, and the corresponding readings of the galvanometer as ordinates.

The spectral width of the slits was 0.4 μ in the region of 3 μ and 0.2 μ in the region of 4 μ.

It proved to be possible using a lithium fluoride prism to obtain a well defined double structure of the band 4.3 μ with a spectral interval of 300 Å. The sensitivity of the spectrophone was such that the minimum interval for which it was possible to detect this band with the help of the prism was about 80 Å. A further improvement of the method consisted in using a more perfect cell, a resonance microphone and a four-valve amplifier with a larger amplification factor ([4]) than in the case of the three-valve amplifier used before. The improvement of the cell consisted in covering the microphone by a very thin aluminium foil; a thin plane fluorite plate has been used as a window. The six sides of the plate were polished and all but the two side faces, aluminized. The radiation was let directly through the side faces from the monochromator slit, close to which the cell was placed.

The radiation that entered into the cell could not go out and, owing to numerous refraction from the polished walls, a long path was obtained.

The cell was made of steel; its walls were very thick to keep out external noises from the microphone (Fig. 3).

Exceedingly weak bands, which usually can only be observed in many-meter thick layers, lend themselves to the investigation with the help of the described cell. With automatic registration a rapid electric indicator can be used to advantage for recording the spectrum in a few seconds, as the Tyndall-Röntgen effect is practically free from inertia.

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TECHNICAL PHYSICS

VALVE AMPLIFIER FOR A SPECTROPHONE

By S. A. COGAN, S. M. LUCHIN and V. I. SIFOROV

(Communicated by A. N. Lebedev, Member of the Academy, 8.VIII.1944)

M. L. Veingerov has described a spectrophone—an apparatus for investigating the absorption spectra of gases in the infra-red, and for quantitative as well as qualitatative analysis of complex mixtures of gases (1).

The alternating electromotive force formed at the output from this apparatus is very small. For measuring this electromotive force we designed a four-stage amplifier of low frequency with metallic valves. Metallic valves secure a greater amplification at a low-noise level. Moreover, they are sufficiently well screened from outward electromagnetic interference. The microphone effect, especially objectionable in powerful amplifiers, is quite insignificant in these valves. The amplifier may be applied for amplifying the electromotive forces

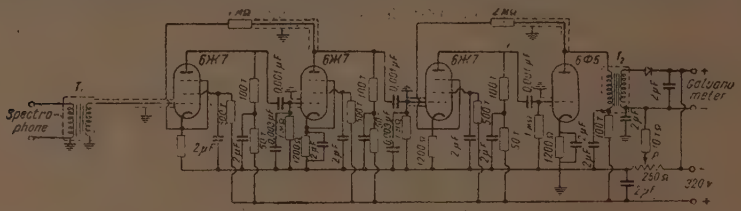

Fig. 1. Scheme of amplifier to spectrophone

formed either by a low-ohm electrodynamic microphone, or by any high-ohm generator, for which purpose the input only has to be suitably changed.

The wiring diagram for an amplifier is shown in Fig. 1. The microphone of the spectrophone is connected with the input of the amplifier by means of an armoured cable, having a coupling at its end. The input microphone transformer T_1 (coefficient of transformation is 30) is placed on the chassis of the amplifier hard by the first stage. For annihilating the interference of electromagnetic fields which often exist in buildings having an a. c. network, the transformer is placed into a thick-walled iron casing. Its winding is made according to the scheme shown in Fig. 2. Such winding considerably reduces the influence of outer fields, because the electromotive force induced by the outer fields in the first half of the winding has a direction opposite to that induced in the second half.

The amplifier is mounted on an iron framework. In the exterior part of this framework the transformers, the condensers of 2 μF and the valves are located, and in the interior part are the other condensers and the resistances; the valves and the transformers are covered by an iron lid which reduces the inductive interference. The interference which sometimes still penetrates through the screens

can be practically eliminated by finding out the best location of the amplifier with regard to the resultant of all the interferences existing in the given place. For this purpose the amplifier has to be turned in the horizontal and vertical planes until the effect of the interferences will be as small as possible.

The first three stages of the amplifier are operated on the valves 6G7; for

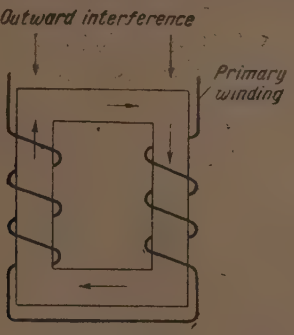

Fig. 2. Core of microphone transformer (the secondary winding is not shown)

the last one the valve 6F5 is used. Active resistances are chosen as an anode load for the first three valves; and for the last valve a reducing transformer T_2 is used (the transformation coefficient is 6). The secondary winding of this transformer operates for the one-timed cuprox rectifier, and to the clamps of the latter a galvanometer is joined. For compensation of the effect of noises a small direct potential difference is applied to the galvanometer. Its value is controlled by a potentiometer P_1.

For increasing the stability of the amplification factor a negative feed-back is used. It is carried out by applying alternating potential of the anode of the second valve to the cathode resistance of the first, and of the anode of the last valve to the cathode resistance of the third one. The amplification factor of the amplifier as a whole, including the input and the output transformers, is about four millions.

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GEOPHYSICS

CONVECTIONAL SEA CURRENTS IN A MONSOON FIELD

By W. W. SHOULEJKIN, Corresponding Member of the Academy

Apparently, admiral Makarov was the first to make a detailed comparison of several factors which cause different sea currents by their action on the sea waters. In his fundamental work «*The Vitjaz» and the Pacific* he analysed the physico-geographical situation in the region of some well-known currents. He noted the part played by the immediate influence of the wind on the surface as well as that played by convection arising from the difference in temperature and salinity of the ocean waters. Makarov attempted also to reproduce such convectional currents in the laboratory by means of a simple and ingeneous apparatus (1).

By now we have general equations of the hydrodynamics of sea currents, created by Scandinavian geophysists (2), as well as correlations between the thermal characteristics of the sea and its monsoon field (3), established in this country. Therefore, it is very interesting to approach the problem set by Makarov from a new angle, and to give quantitative characteristics for convection currents — analogous to those found by us for drift currents arising in the monsoon field (4).

We shall here examine only the winter season which is the most interesting for our seas. Under the influence of the heat accumulated by the sea during the warm season and radiated from the surface during the cold one the atmosphere over a certain point of the sea will be heated τ_1° above the temperature which it would assume if there were no oceans on the globe.

Similar to our previous researches (3), we shall visualize the atmosphere schematically as a film capable of conducting heat, that is of receiving it from the sea and radiating into space.

If all the globe were covered with water, the temperature of the air above it would be Θ° higher than the temperature over a completely dry globe. Making use of what we have in (3), we write down

$$\tau_1/\Theta = 1 - N_1 I_0(\varkappa_1 r) \tag{A}$$

where

$$N_1 = \frac{\mu K_1(\varkappa_2 R)}{I_1(\varkappa_1 R) K_0(\varkappa_2 R) + \mu I_0(\varkappa_1 R) K_1(\varkappa_2 R)} \tag{B}$$

The symbols I_0, I_1, K_0 and K_1 denote Bessel and McDonald's functions, r being the radius-vector of the corresponding point of a circular sea; R, the radius of the circle bounding the whole sea. Then

$$\varkappa_1^2 = \frac{\alpha + \sigma}{AH}, \quad \varkappa_2^2 = \frac{\sigma}{AH}, \quad \mu = \frac{\varkappa_2}{\varkappa_1} \tag{C}$$

where α is the constant of heat interchange between the sea and the atmosphere; σ, the constant of radiation; AH, a coefficient of the heat conduction of the

«film». The quantity Θ may be expressed through α, σ and the temperature of the surface water τ_w measured by taking for «zero» the temperature of our atmospheric film over a dry globe:

$$\Theta = \frac{\tau_w}{1 + (\sigma/\alpha)} \qquad (D)$$

Owing to differences in the temperatures determined by the equation (A), a different amount of heat is carried off from different sea zones in the same period. In the above-mentioned work we have determined the heat current dq/dt that rises from an area bounded by two arcs of radii r and $r + dr$, respectively, and by two radii forming an angle ψ in radians.

The heat current dq/dt from a unit surface of the sea will consequently be

$$dq/dt = \alpha(\tau_w - \tau_1) \qquad (1)$$

or, according to (A) and (D)

$$dq/dt = \alpha\tau_w - \alpha\Theta\,[1 - N_1 I_0(\varkappa_1 r)] \approx \alpha\tau_w N_1 I_0(\varkappa_1 r) \qquad (2)$$

because $\Theta \approx t_w$.

Generally speaking, the heat current varies with the time of the year reaching its maximum in the coldest season and falling to zero in the intermediate time between seasons. Approximately we may assume it to obey a cosinusoidal law:

$$dq/dt = f \cos \frac{2\pi}{T} t \qquad (3)$$

where the period T is a year, *i. e.* 3.16×10^7 seconds.

It is easy to show that with the loss of heat q there must be a change in the pressure p which the water exerts on an area located at a depth, below which the seasonal temperature variations are not felt. The relation between these quantities can be expressed by a simple formula

$$dp/dq = gn/c \qquad (4)$$

Here n denotes the coefficient of cubic expansion of the water; c, the specific heat of the water; g, the acceleration in the gravity field.

From the relations (2), (3) and (4) we can write:

$$dp/dt = \left| g\alpha n \frac{\tau_w}{c} \right|_{\max} N_1 \cos\left(\frac{2\pi}{T} t\right) I_0(\varkappa_1 r) \qquad (5)$$

The water pressure per unit surface at the distance r from the centre of a circular sea should vary according to this formula, if there is no noticeable heat exchange between the water masses in the horizontal plane.

The complete change in pressure for half a year will, according to (5), be equal to

$$\Delta P = \frac{2}{\pi} \left| g\alpha n \frac{\tau_w}{c} \right|_{\max} N_1 I_0(\varkappa_1 r) = A I_0(\varkappa_1 r) \qquad (6)$$

For simplifying the calculation we shall assume that in summer there is no considerable difference in the heating of water at various distances from the shore. Then it will become possible to determine the horizontal pressure gradient arising on the sea in winter owing to the unequal pressure growth in various concentric sea zones.

Indeed, by virtue of (6) we have

$$\operatorname{grad}(\Delta P) = A\varkappa_1 I_1(\varkappa_1 r) \qquad (7)$$

This horizontal pressure gradient will call into being a convection current moving anti-clockwise. The current lines in the plane will be shaped as concentric circles, provided the sea depth may be considered as constant, or is only a function of the radius-vector r and does not depend on the azimuth of

the point, *i. e.* if the sea bottom is either horizontally flat or conic with its hollow in the centre of the sea. The vertical distribution of the current velocities will, of course, depend on the vertical distribution of temperatures which cannot be schematically analysed here. It may be affirmed, however, that the order of the convection current velocity must be determined by the equation

$$w_{\text{conv}} \approx \frac{1}{2\delta\omega} \operatorname{grad}(\Delta P) \qquad (8)$$

where $\bar{\omega}$ is the projection of the Earth's angular velocity on the vertical in the given point. Or, according to (7) and (8):

$$w_{\text{conv}} = \frac{A x_1}{2\delta\omega} I_1(x_1 r) \qquad (9)$$

Let us now apply our calculations to numerical values and suppose that in our relations: $\alpha = 6.8 \times 10^{-5}$; $\sigma = 3.3 \times 10^{-4}$. For the seas in the medium latitudes of the globe: $\tau_w \approx 24°$; $\bar{\omega} = 5 \times 10^{-5}$. Here τ_w denotes the maximum difference of the water temperature on the surface and the air temperature immediately above the surface of a «dry» globe. This maximum difference occurs at the end of January.

As a result of calculations according to the above formulae, we get for convection currents close to the coast:

R (radius of the sea) . . .	250	1000	2000	3000 km
w_{conv}	1	3	9	22 cm/sec.

These velocities are extremely small as compared to the velocities of currents that are of drift origin: of the currents which are caused near the coasts even by the local monsoons only. to say nothing of temporary winds of cyclonic origin exceeding the mean values.

In some regions of the sea an excessive pressure gradient may arise in the layers of the sea water, owing to special local conditions.

Thus, in a sea whose radius is the smallest among those above-mentioned, the horizontal pressure gradient can reach in winter a tenfold value (about 10^{-3} absolute values) owing to a strong cooling in one region. But even this high gradient, as is obvious from calculations, causes a purely convection velocity — about 10 cm/sec.

Consequently, the currents arising in the monsoon field of a close sea are mainly determined by the mechanical influence of wind on the surface layers of water. The thermal influence creates convection components whose velocity is lower than that of the drift components.

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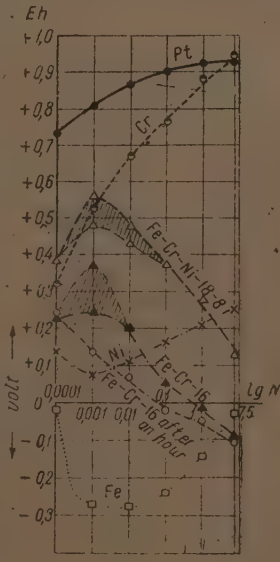
PHYSICAL CHEMISTRY

THE ELECTROCHEMICAL BEHAVIOUR OF STAINLESS STEELS

IV. ELECTRODE POTENTIALS OF STAINLESS STEELS AND THEIR COMPONENTS IN $FeCl_3$ SOLUTIONS

By V. P. BATRAKOV and G. V. AKIMOV, Corresponding Member of the Academy

Ferric chloride is a notoriously strong oxidizing agent. On the other hand, solutions of ferric chloride contain H^+ and Cl^- ions. Therefore these solutions act upon stainless steels and their chief components—chromium, nickel and iron—in two different ways. While the action of the solution as an oxidizing agent is towards a passive state, the hydrogen and chlorine ions, present in it, have an activating influence. For this reason in solutions of ferric chloride just as in solutions of many other oxidizing agents either the passive state sets in completely, or quite intensive localized corrosion occurs (1). Uhlig, on the basis of these properties of ferric chloride solutions, developed a method of testing stainless steel for its tendency toward highly localized corrosion, *i. e.* toward pitting(2).



In the present investigation we had as our goal a systematic study of the electrode potentials of typical stainless steels in $FeCl_3$ solutions of different concentrations. Electrode potentials, as is known, prove often to be good indicators of the active and the passive state of a metal.

The composition of the metals and their treatment have already been described elsewhere (3). A computation of the diffusion potentials between the $FeCl_3$ solutions and KCl that we made with the Henderson equation, showed that the magnitude of these potentials does not exceed several millivolts. Moreover, acidification of $FeCl_3$ with hydrochloric acid only slightly alters their magnitude. Hence we did not introduce a correction for the diffusion potentials.

The experimental results are given in the figure. The curve for platinum shows that the starting point lies close to the normal oxidation-reduction potential $Fe^{\cdots} \rightleftarrows Fe^{\cdot\cdot}$ (+0.74 V), the change in potential being due, mainly, to the change in acidity of the solution upon increasing the concentration of $FeCl_3$. Iron corrodes intensively in $FeCl_3$ solutions. Its electrode potential curve shows that the increase in the concentration of H^+ ions and Cl^- ions upon increasing the concentration of $FeCl_3$ strongly activizes the iron, probably owing to the destruction of the primary protective film. The rise in potential from 0.01 *N* onwards accompanied by ever increas-

ing corrosion. may be explained by the increase in potential of the cathode areas due both to the rise in the oxidation-reduction potential of the solution and to strong cathode polarization (high values of the corrosion current). Chromium does not corrode in all the investigated concentrations. An increase in the concentration of $FeCl_3$ sharply raises the value of the electrode potential, which appears to be largely connected with an improvement in the protective film. At a concentration of 7.5 *N* the potential of chromium is already found to be equal to that of platinum. The values of the electrode potentials for nickel and the form of the resulting curve resemble those for the same metals in solutions of nitric acid ([3]), except for the fact that the last segment which sharply rises nearly to the value for platinum, is absent here.

In the concentration range 0.0001—0.01 *N*, chromium steel Fe—Cr 16 reveals an unstable value of the potential (broken line) shortly after the start of an experiment. Further, the curve drops sharply. If the experimental measurements are compared after an hour, the entire curve is found to drop continuously. The steel corrodes in the investigated solutions. What is more, the higher the concentration, the greater the corrosion. Thus, upon increasing the concentration of $FeCl_3$ the activating action of H^+ and Cl^- ions prevails over the action connected with an increase in the oxidizing ability of the solution. The curve for steel 18-8 rises somewhat at first and is parallel to the curve for chromium. Thus, upon increasing the concentration of $FeCl_3$ to 0.001 *N* the protective film here, just as in the case of chromium, sharply improves. However, upon further increasing the concentration the curve drops, thus revealing a process of activation. At this point highly localized pitting appears. Thus, only a few spots on the surface of the steel are activated, nearly the entire surface remaining in the passive state. Owing to this, the curve for steel 18-8 too, notwithstanding the fact that it is of the same falling type, lies much higher (some 250—300 mV) than the curve for the high chromium steel Fe—Cr 16. Worthly of note is the great difference in behaviour of steel Fe—Cr 16, and especially steel 18-8, in solutions of $FeCl_3$ and in solutions of HNO_3. The electrode potentials of the investigated metals in solutions of $FeCl_3$ change differently with time. The electrode potentials of platinum are comparatively stable. The potentials of iron in a 0.001 *N* solution change markedly (by approximately 100 mV in a negative direction) after an hour; in other solutions the potentials are quite stable. The potentials of chromium increase somewhat in nobility with time. In a 0.001*N* solution this change amounts to 80—90 mV in one hour. The potentials of nickel are quite stable and do not change by more than 20—30 mV in the course of an hour. The potentials of the steel Fe—Cr 16 change considerably in certain solutions in the direction of negative values (by 120 mV in a 0.01 *N* solution after one hour). The potentials of steel 18-8 increase somewhat in nobility in 0.0001 and 0.001 *N* solutions and become noticeably less noble in solutions of higher concentration (by approximately 100 mV in the course of one hour).

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GEOCHEMISTRY

ON THE GEOCHEMISTRY OF STRONTIUM

By A. P. VINOGRADOV, Corresponding Member of the Academy, and T. F. BOROVICK-ROMANOVA

Strontium in the form of celestine is of wide occurrence in sedimentary rocks of most systems. Within the Soviet Union celestine has been described from the Silurian deposits of Yakutia (1), the Upper Devonian deposits of the Moscow Basin (2), the Permian deposits of the Volga-Ural province and Caspian lowland (3,4), the Tertiary-Cretaceous rocks of Central Asia (5,6), *etc.*

As a result of mineralogical studies it has been found that celestine occurs there either in the form of lenses, in normal beds of gypsum or dolomite, or as fissure fillings, celestine concretions or cement of various rocks—sandstones, marls, fossil remains of organisms. From the relations between celestine and the rock minerals it could clearly be seen that in the latter case celestine occurs as a secondary mineral.

The fact of celestine being confined to gypsum, dolomitized limestones and dolomites has also been recorded for numerous foreign deposits of celestine(7,8).

But save for isolated data on the series of halogen sediments of Stassfurt(9), no data are available on the distribution of strontium in a complete section of any definite sedimentary cycle, or geological system.

Consequently, a number of questions concerning the origin of celestine have still remained unsettled.

The authors have attempted to make clear the mode of the distribution of strontium in Lower Permian and Carboniferous deposits. They had at their disposal cores from a number of holes drilled within the Verkhne-Uslonsky structure (on the right bank of the Volga, near the town of Kazan) by the geological party of the Tatarian Geological Trust. The holes penetrated through Kungurian anhydrites, Artinskian dolomites, and dolomites of the Carboniferous C_3^{III}, C_3^{II}, C_3^{I}, to a total depth of about 300 m. Holes 4, 3, 2, 9 are spaced hundreds of meters apart, in a N—S direction. The Kungurian deposits are represented by crystalline, hard blue anhydrites, partly with fissures filled with gypsum, dolomites, and layers of grey gypsum and intercalations of gypsose dolomites. The Artinskian dolomites are crystalline, hard, occasionally porous, sometimes with impressions of organisms, with intercalations of gypsose limestones. The Carboniferous limestones and dolomites are well distinguishable by fossil remains, composing the *Schwagerina*, pseudo-*Fusulina* and *Triticites* horizons.

A study was made of the chemical composition of these rocks, in particular, of the distribution of P, Mn and F. It is of interest to note that there is a correlation in the content of Mg and SO_4 in the limestones. Strontium was determined spectroscopically. As the source of excitation of the spectrum served an alternating current arc with activators (Pfeilsticker's). The sample was placed in a hollow, 3 mm in diameter and 6 mm deep, made in the lower electrode.

Nos.	Rock	Depth in meters	Per cent $SrSO_4$	Age
		Hole No. 4		
8	Limestone	8.23— 13.3	0.25	
10	»	14.2 — 14.79	0.24	
14	Gypsum	20.3 — 28.06	0.37	
21	Anhydrite	37.5 — 38.7	1.00	
23	Dolomite	39.5 — 40.05	0.08	
37	Anhydrite	48.6 — 52.52	0.43	
45	Dolomite	59.85— 60.3	0.25	
51	»	68.1 — 69.08	0.80	P_{kng} from 20.9 to 124.2 m
59	Anhydrite	75.87— 77.44	0.23	
64	»	83.63— 92.5	0.23	
67	Gypsum	96.95— 96.95	0.24	
69	Dolomite	98.95—101.2	0.43	
71	»	104.7 —106.35	1.37	
72	Anhydrite	106.35—115.35	0.48	
76	Dolomite	120.5 —121.95	0.50	
79	Gypsum	129.03—130.07	**0.37**	
87	Limestone	138.15—140.90	**0.90**	
88	Dolomite	140.9 —147.1	0.04	P_{art} from 124.2 to 164.3 m
91	»	150.84—153.21	0.06	
92	»	153.21—161.73	0.12	
93	»	161.73—163.03	0.02	
95	»	164.35—167.85	0.02	C_3^{III} from 164.3 to 181.5 m
97	»	168.6 —173.08	0.13	
104	»	180.53—184.6	0.04	
109	Limestone	192.62—193.12	0.06	
110	Dolomite	193.12—200.4	0.20	
113	»	204.31—204.46	0.08	
120	»	212.3 —212.9	0.05	C_3^{II} from 181.5 to 232.0 m
125	»	215.65—219.91	0.02	
130	Limestone	226.61—228.44	0.43	
131	»	228.44—229.4	0.53	
133	Dolomite	230.0 —230.65	0.08	
135	Limestone	232.0 —244.66	0.37	
137	»	244.8 —245.1	0.08	C_3^{I} from 232.0 m
138	Dolomite	245.6 —246.0	0.07	
		Hole No. 3		
33	Limestone	92.2 —112.45	0.29	
34	Dolomite	112.45—116.75	0.34	P_{kng} to 126.2 m
35	Anhydrite	116.75—119.25	0.65	
39	Dolomite	126.05	**1.00**	
50	»	143.0 —145.1	**3.75**	P_{art} from 126.2 to 165.9 m
52	»	156.0 —160.2	0.25	
55	Limestone	165.9 —170.42	0.05	C_3^{III} from 165.9 to 186.3 m
67	»	188.9 —196.28	0.02	C_3^{II} from 186.3 to 235 m
90	Dolomite	216.8 —220.64	0.02	
109	Limestone	245.66—248.56	2.87	C_3^{I} from 235 m
		Hole No. 2		
10	Gypsum	96.0 — 98.0	0.60	
11	Dolomite	98.65—101.4	0.38	
12	Gypsum	101.4 —103.8	0.65	
13	Anhydrite	103.8 —104.9	0.63	P_{kng} to 132.5 m
	Dolomite	111 19—112.4	0.19	
20	Anhydrite	114.0 —121.0	0.35	

Nos.	Rock	Depth in meters	Per cent $SrSO_4$	Age
26′	Dolomite	132.48—134.16	4.25	P_{art} from 132.5 to 176.0 m
	»	147.25	7.75	
	»	165.0	0.11	
33	»	181.1 —187.83	0.08	C_3^{III} from 176.0 to 194.1 m
39	Limestone	201 —202.7	0.03	C_3^{II} from 194.1 to 243 m
49	»	215.5 —217.8	0.30	
71	»	243.4 —247.2	0.12	
		Hole No. 9		
27	Anhydrite	101.7 —110.2	0 60	P_{xng} to 143.0 m
28	Dolomite	110.2 —110.93	5.62	
30	Gypsum	114.39—117.69	1.87	
31	Dolomite	117.69—120.7	14.25	
32	Gypsum	120.7 —123.68	2.80	
35	Dolomite	140 —143	0.01	P_{art} from 143.0 to 184.8 m
38	Limestone	163.5 —164 0	0.05	
40	Dolomite	179.4 —184.8	0.38	
48	»	221.3 —222.94	0.01	C_3^{II} from 207.5 to 254.9 m
76	»	251.5 —252.9	1.38	

Amperage, 10 A; voltage, 220 V. The spectrograms were made on a Q-24 quartz spectrograph. The 4607.342 Å line of Sr was used for the analysis. To equalize the evaporation, Na_2SO_4 was added* to the specimens and standards at a ratio of 1 : 1. To evaluate the Sr content, the «internal standard» method was applied. The internal standard was yttrium (Yt = 4643.69 Å). The measurement of the blackening of the lines was made microphotometrically. The error of measurement was ±10 per cent**.

The Carboniferous dolomites in all the holes showed the least amount of Sr—on the average about 0.05 per cent, and a Ca/Sr ratio approaching 400. The Kungurian rocks, chiefly anhydrites, contained strontium at an amount several times greater, on the average about 0.3 per cent, and had a Ca/Sr ratio approaching 100, *i. e.* near the Ca/Sr in the sea where it is equal to 33. The isomorphism of celestine and anhydrite should be remembered at this point. The largest concentration of strontium was found in the upper portions (in beds about 15—20 m thick) of Artinskian dolomites, directly underlying the Kungurian anhydrite-gypsum beds. The Ca/Sr ratio attains here 3. In hole No. 9 the maximum Sr content is found in dolomites and gypsum, referred by the geologists of Verkhny Uslon to the bottom of Kungurian deposits. In the authors opinion, however, the boundary between the Kungurian and Artinskian deposits should be drawn here somewhat lower. A study of the Artinskian and Kungurian rocks from other localities (Kamskoye Ustye, Shugurovo, Ishimbaevo, *etc.*) offered a similar picture. It is of interest to note that the Artinskian waters of Ishimbay have been found to be saturated with $SrSO_4$(1°). Thus, in the upper portion of the Artinskian deposits, at their boundary with the Kungurian anhydrites of the Verkhny

* It was not necessary to introduce Na_2SO_4 and Yt. In these cases the evaluation of the strontium content was made from the ratio of the intensity of the background of the spectrograph near the lines to the 4607.342 Å line of Sr. The error was somewhat higher, but the time of determination was considerably reduced.

** The assistance of S. A. Borovick in spectroscopic work is gratefully acknowledged.

Uslon rocks, *etc.*, a celestine horizon was discovered* which is an excellent geological correlative.

The microscopic examination, especially that of specimens rich in celestine, showed the celestine to occur in an association with dolomite, gypsum, in the form of irregularly bounded grains and small crystals, not infrequently filling fissures in dolomite, over-growing around dolomite rhombohedra. A similar picture was on several occasions observed by number of investigators and has been well studied from the mineralogical standpoint by L. M. Miropolsky. All that has been said here justifies the assumption made on the basis of mineralogical data, *viz.* that the celestine had been precipitated from solution upon the formation of dolomite and prior to the sedimentation of gypsum or anhydrite. Finally, from the chemical standpoint, from the data available the following may be inferred. Sea water contains $1.3 \cdot 10^{-3}$ per cent Sr ([11]); it is not saturated with $SrSO_4$, for the amount required to this effect should be approximately five times as great.

During the evaporation of closed sea basins in the first stage of crystallization Sr does not fall out with $CaCO_3$ sediments, since the solubility of $SrCO_3$ increases along with a concentration of the solution and leaves the solubility of $CaCO_3$ somewhat behind.

Along with the concentration of the sea water (up to 15 per cent NaCl) the solubility of $SrSO_4$ increases about 15 times; and that of gypsum, 4—5 times. With a density near 1.120, by the moment of saturation of the brine with gypsum (or anhydrite)([12]) $SrSO_4$ begins to precipitate. The mode of precipitation of $SrSO_4$ depends on the depth, volume of the basin, *etc.* Thus, according to geological, mineralogical and chemical data $SrSO_4$ is precipitated from brines of the sea type, penetrating the carbonate bottom sediments, by the moment of their saturation with gypsum (or anhydrite).

Therefore the well preserved upper parts of the carbonate rocks directly underlying the anhydrite-gypsum beds must be particularly rich in $SrSO_4$.

$SrSO_4$ being readily soluble in solutions of NaCl, *etc.*, the strontium migrates from the sediments in question with waters forming secondary deposits, largely with gypsums.

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* It is of interest to note the second celestine horizon in the upper part of the *Tirolites* horizon among partly gypsose and dolomitized limestones.

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HYDROGEOLOGY

A CONTRIBUTION TO THE PROBLEM OF THE HYDROGEOLOGICAL CONDITIONS OF FORMATION AND PRESERVATION OF OIL DEPOSITS

By N. K. IGNATOVICH

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1. In order that the oil which has originally been formed in a disseminated state in different rocks may accumulate into a deposit, the underground waters at work should be in motion (under definite conditions prevalent in the reservoir rocks). But after a deposit has been formed, it will not be safely preserved for a long time unless the accumulation is hydrogeologically isolated, or, as it is sometimes termed, «sealed», for otherwise there is further migration of oil; and if water circulation becomes active, owing to an exchange of water with the surface, a gradual destruction of the oil accumulation begins, as is the same of various other mineral substances, decomposed and removed from the enclosing rocks.

2. The migration and destruction of oil deposit is as regional a phenomenon as the formation of oil and oil accumulations. Very often structure and reservoir rocks seem to be favourable and even oil shows are observed, yet no workable amounts of oil are discovered. Thus, many structures had possibly once been oil-bearing, but in the course of geological and hydrogeological processes involving circulation of underground waters, weathering process, bacterial activity, *etc.*, these oil accumulations were gradually exhausted and destroyed (*e. g.* in the Carboniferous—the Issa structure in the Penza region, certain structures of the Saratov region, in the Permian—Zmeyevka, Tatarian ASSR and others).

3. Complexes of strata which in the past geological time were and still are within the zone of active water exchange, and where hydrocarbonate and sulphate waters are prevalent, offer no favourable environment or medium either for the formation or preservation of oil. Unlike this, rock complexes which in the geological past were located in a closed zone, not isolated from the earth's surface, where the migration of underground waters proceeded and still proceeds at a stagnant water regime, such zones are characterized under platform conditions by a development of ancient chlorine-sodium-calcium waters, and in folded areas, by alkaline, geologically young, renewed waters.

Any oil-bearing province, as well as any separate oil accumulation, may on the basis of the regional conditions be distinguished and classed according to the respective value of these agencies which are or are not beneficial for the preservation of oil, leading in the latter case to a destruction of oil accumulations.

To give an example, let us make a brief review of the hydrogeological peculiarities of the Russian platform and the Apsheron Peninsula.

4. All over the Russian platform the oil deposits are characterized by a definite, persistent type of chlorine-sodium-calcium brines, whose degree of mineralization does not fall below 100 g/l and usually attains 150—200 g/l and more.

Waters and brines of this type most frequently contain bromine and radium. Within the platform Devonian, Carboniferous and occasionally also Permian rocks are saturated by them in the zones where the rocks lie at a considerable depth, as well as in depressions and troughs where a stagnant water regime has been recorded. The rocks lying nearer to the surface, located in the zone of impeded water exchange, and still higher up, of an active one, produce waters with a lower mineralization, which in their chemical composition are transitionary from hydrocarbonate sulphate to sulphate-chloride waters.

5. The most freshened is the Palaeozoic complex in the west of the platform, where Devonian and Carboniferous deposits, exposed at the surface, have during a prolonged geological time been subject to an active influence of exogenetic agencies. The latter were manifest not only within the Moscow artesian basin, but also further south-east, in the Tambov, Penza, Saratov and other regions, where the Palaeo-Mesozoic break also occurred*. The existence of a deep Cis-Ural downwarping with very thick Lower Permian deposits is the reason why the western slope of the Urals had no active influence upon the formation of hydrogeological conditions of the Devonian and Carboniferous deposits within the platform. Only from the side of the western slope of the Ufa plateau, in a direction towards the Volga along the near-Kama belt, a zone of water exchange with the surface may be supposed to exist in Permian and partly Carboniferous deposits.

6. The Permian deposits which are nearest to the surface over the greater part of the Russian platform are involved in active water exchange, and have for prolonged geological time produced an impeded underground discharge. Numerous salt springs still take part in the general process of freshening Permian aquifers. Only those regions which adjoin the Caspian depression from the north and the zones of the deep Cis-Ural downwarping and in the north the region near the Timan Range seem to be favourable from the hydrogeological standpoint to the conditions of the formation and preservation of oil accumulations.

7. As compared to the Permian, the Carboniferous deposits overlain by Permian ones, are under more favourable conditions in so far as water regime is concerned which is necessary for the preservation of oil accumulations. As to the areas of the Carboniferous which show an active water exchange and an extensive development of fresh hydrocarbonate waters (the Moscow Basin and the territories adjoining it), these seem to be of a very small practical interest from the standpoint of the presence of oil. Territories where the conditions of possible oil content are intermediate for the Carboniferous, are located in regions which include local centres of freshening and intensive circulation of underground waters, but do not change the general background of a slackened water exchange with the surface (regions located on the platform north-east and east of areas of active water exchange).

8. In the eastern part of the platform the oil deposits of the Palaeozoic were protected by the deep Cis-Ural downwarping against the effect of adverse hydrogeological factors. The Permian and partly Carboniferous deposits within the above-named Ufa—Kama belt are possibly in the phase of influence of these agencies. In the regions adjoining the Caspian depression from the north, the sluggish underground discharge in the southern direction meets with conditions of hydrogeologically isolated structures. The latter were subject to no erosion for a prolonged geological time, and the oil accumulations were not destroyed.

9. The conditions are much different with regard to the Devonian. If in the western part of the Russian platform the territories of the highest (structurally) attitude of the Devonian are left out of consideration, — that is, in those places where the Devonian has since a remote geological time been subject to a strong influence of surface factors, — within the remaining territory, in the Second Baku in particular, the Devonian should, according to hydrogeological

* In 1938—1940 the author carried out on the Russian platform investigations of the regularities in the distribution of underground waters, compiled a large number of different hydrogeological and hydrogeochemical maps of some stratigraphical complexes, and also for different height intervals—maps of horizontal sections.

characteristics, be under most favourable conditions with regard to oil occurrence. However, it should be borne in mind that where the Devonian occurs at a considerable depth, while conditions necessary for a closed migration of underground waters, which could bring about an accumulation of oil, were lacking in the past, oil may be preserved in the rock only in a disseminated condition. An extensive development of brines of the chlorine-sodium-calcium type under the given conditions will be accompanied by no formation of oil deposits.

As an example of the conditions prevalent in folded areas, let us consider here the hydrogeological peculiarities of the Apsheron Peninsula.

10. The highly mineralized chlorine-sodium-calcium waters that occur in the Apsheron Peninsula in the productive strata of Upper Tertiary age are alien to the enclosing rocks both according to their nature and degree of saturation; the latter cannot form brines of the above concentration. Waters and brines of this type have evidently penetrated from below, owing to favourable tectonic conditions and a suitable hydrodynamic regime. Migration of underground waters has been taking place during a prolonged geological time towards the Caspian depression from the Main Caucasus in a direction to the south-east, these waters gradually displacing in deep zones the ancient chlorine-sodium-calcium waters.

11. The most intense circulation of underground waters was proceeding in the past and is taking place now at the periphery of the Apsheron Peninsula proper. The underground discharge of the northern slope of the Main Caucasus which proceeds not only along the dip, but along the strike of the rocks to the south-east as well, produces in the Caspian lowland a number of large centres of a very considerable amount in water and of freshening of the Tertiary complexes (*e. g.* basin of artesian waters of Kuba-Khachmas Shollar-Samur, studied by this author). On the southern slope of the Main Caucasus the centres of the corresponding underground discharge with a deep circulation seem to pass also along the Shemakha-Sangachal belt. The mud volcanoes which are numerous here are as it were «windows» of deep water-bearing complexes with impeded discharge. The alkaline and other slightly mineralized waters in a number of regions and in some mud volcanoes are evidence of the fact that the influence of the hydrodynamic agencies leads here to a removal, displacement of the ancient chlorine-sodium-calcium waters and oil.

12. If the Apsheron Peninsula were faulted to the same degree as, *e. g.*, the Cheleken island, if there existed here as on the Cheleken conditions of an active circulation of underground waters, we would have on the Apsheron Peninsula numerous thermal springs and other springs with a deep circulation, but this region would not necessarily be endowed with the remarkable oil content it actually has.

13. In the past, the region of the Apsheron Peninsula accumulated oil from a vast territory of the south-eastern extremity of the Caucasus. The excellent reservoir rocks of Apsheron, which are hydrogeologically isolated from the surface, were a huge «trap» for oil, owing to a slow migration of the closed type of the ancient waters and oil directed towards Apsheron. The process of differentiation of water from oil may possibly still proceed in deep zones of Apsheron. In definite regions, *e. g.* at the periphery of Apsheron, where the circulation was more intensive and connected with the earth's surface, there went on a process of impoverishment and destruction of oil accumulations. The oil deposits of the Eastern Cis-Caucasia (Grozny, Daghestan), as compared to the Apsheron deposits, are under conditions of a stronger influence of hydrodynamic factors which interfere with the preservation of oil deposit.

14. In the course of his study of the hydrogeological conditions of petroliferous provinces, the author revealed a regional relationship between the distribution of oil deposits and the elements of zoning of underground waters (of a hydrogeochemical and hydrodynamic nature).

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MINERALOGY

CRYSTALLINE NATURE OF STRUCTURE OF CLAY GROUNDS

By I. V. POPOV

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I. Terminology. Grounds are understood here in the genetic sense, *i. e.* as natural formations produced by weathering processes, other agencies of external geodynamics being also at work.

Under structure are generally meant such features of a ground, as its

Fig. 1. Cryptostructural anchicrystalline microaggregates of montmorillonite Ca clay; optical orientation: *a*, anisotropic; *b*, isotropic bands (the drawing made at a magnification × 920)

size, shape and relative spatial arrangement of the individual constituents.

As elementary particles in grounds should be considered only those which are crystalline individuals. They may be submicroscopic, microscopic or macroscopic. The aggregate grains may be cryptostructural, microstructural or macrostructural, respectively.

II. Material and Method. To microscopic examination were subjected crypto- and microstructural aggregates in grounds: in montmorillonite clay (from the village Askan, Georgia) «askangel», and kaolinite clay — commercial kaolin, both saturated with Ca and Na. The choice was made on account of the differences in their crystalline structure [3] and exchange capacity with regard to cations.

The different physical-chemical states of clay were brought about by saturat-

ing their exchange capacity either with calcium or with sodium, and by varyin the concentration of electrolytes in the medium.

The physical methods applied consisted in moistening and drying.

The microscopic preparations were made by mixing on an object-glass with water (or with a definite solution) a small amount of clay which was subsequently covered with a cover glass. If a given liquid had to be replaced or washed out from the preparation, this was made by adsorbing the liquid with blotting paper introduced to the edge of the cover glass, or by instilling under the glass with a pipette some drops of the requisite liquid.

The method of examining the structures that formed upon the drying of the suspension placed between the two glasses has been borrowed from Sideri (1).

III. Results. The results of observations were as follows.

1. The montmorillonite Ca and Na clays are always easily distinguishable

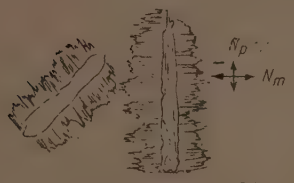

Fig. 2. Cryptostructural anchicrystalline anisotropic grain of montmorillonite Ca clay upon treatment with Na solution and washing of electrolyte

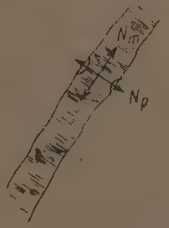

Fig. 3. Cryptostructural microaggregates of montmorillonite Ca clay formed upon drying the aqueous clay suspension between glasses. Structure swelled in water. Optical orientation shown

at high and medium magnifications, and often at low magnification as well.

The aggregates of Ca clays are anisotropic (Fig. 1). Their size is from 200 to 50 μ and less. They very closely resemble crystalline flakes and are mostly of a banded polysynthetic structure, being made up of alternating anisotropic and amorphous bands. A fine striation is discernible across the anisotropic bands.

Such flakes were present in natural askangel, and upon a treatment with a $CaCl_2$ solution they were found to make up the whole of the specimen. Their anisotropy was spontaneous. When treated with a NaCl solution on a filter or on an object-glass the flakes were found to be destroyed (Fig. 2).

Upon drying, the grains were reduced in size, and when moistened, again they swelled to a considerable extent across the bands, and in a lesser degree along the latter. No diffusion, even upon stirring or slight grinding, could be observed.

The swelling was accompanied by a reduced intensity of the interference colours, and the drying by an increase in the latter.

The extinction is always straight, the sign of the zone relative to the fine cross-striation is positive. The clay in water had $N_g' - N_p'$ from 0.005 to 0.006. In some cases it was possible to obtain a biaxial pattern in converging light. The optical character was positive. The optic axes plane lay across the striation (Fig. 1).

Some cryptostructural grains displayed the so-called aggregate polarization.

2. A montmorillonite Na clay mixed with water consisted of uniform grains, 1 μ and smaller in size, partly gathered into unstable clots and flakes. In such aggregates no double refraction was observed.

Strips of clay dried between glasses showed a luminous iridescent interference colour. Upon repeated moistening they swelled rapidly and in a high degree across the bands, and to a very small extent, along the latter. The swelling of the bands which were not torn off from the glass, was considerable but limited

yet, 5—7 times. The bands torn off the place of their formation became diffuse. Complete diffusion of the aggregate was preceded by no change in the optic orientation.

In the clay bands swollen in water ruptures were formed along the cross-striation. The optic axes plane in the swollen bands lay across them (along the striation). The optic character was positive (Fig. 3). Upon being moistened with apolar liquids, no swelling took place.

In the Na clay mixed with concentrated solutions of electrolytes with a univalent cation (up to 7 N) the aggregates were in the form of clots; they were always isotropic.

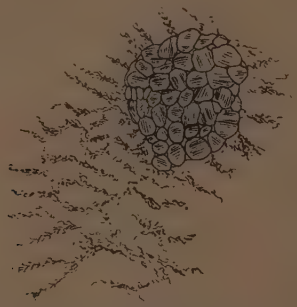

Fig. 4. Montmorillonite and kaolinite clays, simultaneously subjected to a similar treatment with the solution of $CaCl_2$

Na clay, pressed between filter paper, upon drying showed high interference colours. Moistened again with water it swelled rapidly, showing a banded structure. The optic orientation was similar in all the bands; elongation was positive (N_g'), extinction, straight. The direction of N_p, corresponding to the crystalline axis c, was perpendicular to the pressure plane.

Na clay, having the consistence of vaseline at room temperature, pressed down with a cover glass showed an unequal interference luminescence. At different parts arranged in spots the optical orientation was different.

3. Montmorillonite Na clay, precipitated with Ca electrolytes, contained a great number of anisotropic grains characteristic of Ca clay, described above.

4. There were no appreciable differences between the aggregates in kaolinite Ca and Na clays. They were very small, birefringent, sometimes in the form of a «rouleau». In Ca kaolin, upon the action of strong solutions of electrolytes, flexible chains resembling moss were formed. The difference of aggregates in kaolinite and montmorillonite Ca clays is well seen in Fig. 4.

IV. Discussion of Results and Conclusions. Such optically anisotropic objects as obtained by the author from montmorillonite Na clay were assigned by Sideri [1] to mesomorphic formations described by Friedel [3]. However, they are distinguished from mesomorphous bodies by a biaxiality with a (—) sign, the presence of extinction directions, spontaneous formation, the relation between shape and structure, and finally in that they are neither liquid nor paste-like, as Friedel characterizes substances in a mesomorphic state. The same features are inherent also in anisotropic cryptostructures in Na clay; their formation, however, is not spontaneous but takes place under the orienting influence of its boundary surfaces with glass or air.

Thus, the cryptostructures observed by the author are no isomorphous objects either in Ca, or in Na montmorillonite clay. They bear a considerably greater resemblance to crystals of micas and chloritoids which are also laminated crystalline structures. In the latter no bond of an ionic type [2] can exist between

the layers of the crystalline attice unless intermediaries—cations placed between the layers—are concerned.

Univalent cations in micas produce a comparatively weak bond which does not prevent perfect cleavage. Bivalent cations in chloritoids bind the elementary packet considerably more solidly, so that their cleavage and elasticity are considerably lower («brittle micas»).

The different rôle of Na and Ca cations in montmorillonite clay accounts for the different attitude of their cryptostructural aggregates to water.

The bond produced by univalent cations does not prevent the swelling of montmorillonite Na aggregates and their complete peptization. The Ca cations form a more solid bond, hence the cryptostructure in water swells, but is not destroyed.

Thus, the cryptostructural aggregation in montmorillonite clays should be considered as the formation of a heterogeneous crystalline structure capable to change its intralatticé distances.

Until a more detailed study of the nature of the properties of such objects has been made, we have named them anchicrystals *.

Cryptostructural anchicrystalline grains may be monocrystals (or their twins) and aggregates with an aggregate polarization. The anchicrystalline cryptostructures of submicroscopic elementary mineral particles with a laminated crystalline lattice are built up by means of exchange cations, water dipoles taking part. The same type of cryptostructural aggregates may be formed in grounds from humic matter and minerals possessing a laminated type of crystalline lattices.

The heteropolar anchicrystalline bonds of the ionic type should, therefore, be considered as the principal form of structure formation in grounds.

In this way the microscopic grains in grounds may be: (1) elementary crystalline grains (or twin formations); (2) microstructural and crystalline aggregate grains; (3) cryptostructural anchicrystalline aggregate grains; (4) cryptostructural monoanchicrystalline grains; (5) cryptostructural amorphous grains; (6) cryptostructural heterogeneous grains (partly anchicrystalline, partly amorphous).

According to observations of structure objects in kaolin, the bond between elementary or aggregate grains in micro- or macrostructures may be assumed to be of ionic rather than molecular type of crystallization.

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* Rinne's [5] paracrystals are mesomorphous bodies.

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PLANT PHYSIOLOGY

STIMULATION OF THE RESTING SEEDS OF *POLYGONUM BUCHARICUM*

By V. A. NOVIKOV

(Communicated by A. A. Richter, Member of the Academy, 10.V.1944)

Polygonum bucharicum (local name «taran») is a valuable wild tanning plant. Natural growths cannot satisfy the ever increasing demand of tanneries; however, the first attempts to cultivate this plant met with difficulties. The seeds proved incapable to germinate under ordinary conditions, though well-filled and alive. The latter was proved by their active respiration. Consequently, their failure to germinate was caused by the state of rest.

The rest of seeds may be either enforced or profound. Enforced rest may prevent germination of seeds even under suitable humidity and thermal conditions. In this case the seeds are unable to swell or to absorb atmospheric oxygen because of the peculiar structure of their coat. By destroying completely or even partly the tissues of the coat (for example, in alfalfa, melilot, brome-grass, *etc.* the seeds are usually made capable to germinate.

On the assumption that the lack of germinating power was caused by the structure of the coat and that the rest was an enforced one, we carried out the following experiments which were intended to devise a method for breaking the rest of the seeds.

1. Seeds were treated with strong sulphuric acid during 5, 3, 2, 1 and 0.5 minutes. After washing in water, the seeds were placed on filter paper into Petri dishes and tested for germination at a temperature of 20—23° C. There was noted good swelling, but no germination took place.

2. The seeds were gently ground in a mortar with sand and, after having been freed from sand, tested for germination. As in the previous case, good swelling was recorded, but no germination occurred.

These experiments have shown that the injury of the seed-coat with sulphuric acid treatment or mechanical injury is insufficient for breaking the rest, so that the rest proved to be a profound rather than an enforced one.

A profound rest of seeds may be caused either by the presence of special growth inhibiting substances, or, on the contrary, by the failure of formation by the seeds (while still upon the mother-plant) of substances which would stimulate the germination of seeds under favourable environmental conditions.

To become freed of growth inhibiting substances and to form growth stimulating ones, the seeds must pass after-ripening under suitable conditions.

In order to determine what are the conditions suitable for after-ripening and to find out whether seeds become freed of growth inhibiting substances or develop growth stimulating ones during this period, the following experiments were made.

The seeds were soaked in running water at room temperature during several days and were then tested for germination. Good swelling was recorded, but no germination took place.

These experiments have shown that profound rest of the seeds of taran was not caused by water-soluble growth inhibiting substances.

Profound qualitative changes occur in seeds subjected to vernalization (2). The nature of these changes, according to recent investigations, largely consists in the formation of substances of the kind of hormones (3). Vernalization of perennial herbaceous plants of the temperate zone is passed by moistened seeds under the conditions of oxygen respiration at a temperature slightly over 0°C.

In order to find out whether the conditions of vernalization could break the deep rest of the seeds of taran, the following experiments were arranged.

Three lots of seeds weighing 200 g each were taken. One lot was placed into a glass, and a water layer 0.5 cm thick was poured over the seeds. The two remaining lots were spread in layers 0.5—1.0 cm thick between two layers of moist cotton over Koch's dishes. All the three lots were placed into a refrigerator at a temperature from +1° to +3°C. Every seven days samples of seeds were taken from each lot and tested for germination at 20—23°C. None of the lots showed germination after a seven days treatment. After 14 days the seeds kept under water showed no germination, while those which were spread between cotton had germinated to 10 per cent. After 21 days the seeds from under water still remained incapable of germinating, while those kept within cotton had germinated to 20 per cent, even in the refrigerator, and gave additionally 15 per cent germination when placed into a thermostatic oven. After 23 days the seeds kept in cotton have germinated to 35 per cent, while still in frigidaire. On the other hand, the seeds which were submerged did not show germination either in the frigidaire or when tried in the thermostatic oven.

The next experiment on chilling seeds between layers of cotton lasted for 45 days. Every 7 days samples were taken as in the previous experiment. As a result of a 45-day-long chilling, 37 per cent of the seeds germinated.

Consequently, it may be taken for proved that the seeds of taran have a profound rest and that this rest can be broken by the sum of agencies which are cooperative in the case of vernalization, *viz.* by low temperature, access of oxygen and moisture. The minimum duration is 23 days.

As a result of this treatment 35 per cent of the seeds of taran gain germinating capacity.

In order to investigate the nature of the qualitative changes which break the profound rest of the seeds of taran the following observations were made. Respiration was studied at 20°C (after the method of Petterkofer) in swollen seeds which have been chilled for a varying length of time. It has been found that the control seeds evolved 0.9 mg CO_2 pro 1 g per 1 hour, while those chilled during 7 days evolved 0.35 mg; during 17 days, 0.30 mg; during 27 days, 0.30 mg; during 37 days, 0.35 mg.

These results show that the original non-germinating seeds of taran when swollen display a normal intensity of respiration. This testifies once more that untreated seeds contain no inhibiting substances. The sharp drop in respiration after chilling may be regarded as some indication to the formation of certain regulatory substances and as a testimony for the existence of profound chemical changes taking place in the seeds during the period when they are chilled.

It has been found by the writer (unpublished) that swollen seeds of cotton-plant when chilled during 10 days at a temperature of 0°, 5° and even 7° C lose their germinating capacity; when immature and therefore unviable seeds of cotton were germinated in a water-extract prepared of the contents of such chilled seeds, up to 45 per cent of the immature seeds became able to germinate*. This clearly shows that swollen seeds, when chilled, accumulate some growth stimulating substances which are not present in immature seeds.

* The result was the same when the extract had been previously boiled.

Under the assumption that the seeds of taran do not reach full maturity, and by chilling in the swollen state substances of a kind similar to that found in the chilled seeds of cotton are produced in them, we have conducted experiments on germination of the seeds which were not subjected to chilling but placed into an extract (1 : 10) of cotton-seeds which have lost their germinating capacity as the result of chilling.

The seeds of taran treated in this manner have shown a germination amounting in different samples to 6—12 per cent.

Krasnosselskaja and Richter have shown [1] that the awakening of the buds of trees from the winter-rest is caused «by products of cell activity of the kind of hormones which cause profound alterations in the physical-chemical state of the resting cells». The experiments described above show that the breaking of the profound rest of the seeds of taran is similarly due to substances of the type of hormones. The conditions of the formation of these substances are also the conditions of the after-ripening of seeds. The substances which are requisite for the germination of seeds are formed at the latest moment of the period of maturation.

In those cases where they fail to be formed at the time of maturation upon the mother plant, after-ripening becomes an essential requirement.

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ZOOLOGY

ON *CLUPEONELLA DELICATULA* (NORDMANN) OF THE CASPIAN AND THAT OF THE BLACK AND AZOV SEAS

By A. N. SVETOVIDOV

(Communicated by E. N. Pavlovsky, Member of the Academy, 15.IV.1944)

For the past ten years *Clupeonella delicatula* has become of great commercial importance both in the Caspian and in the Azov Seas. Formerly, especially at the pre-revolutionary period, this fish made up scarcely any share of the catches. Along with this species there is also caught in a small quantity *C. engrauliformis*. The third species of this genus, *C. grimmi*, finds no commercial utilization. Thus, the catches of *C. delicatula* in the Caspian may considerably be increased at the expense of these two species which do not occur either in the Black or the Azov Sea.

The genus *Clupeonella* comprises four species: three of them have been mentioned above—*C. delicatula*, *C. engrauliformis* and *C. grimmi*, and besides *C. abrau*. The last inhabits the fresh-water lake Abrau in the vicinity of Novorossyisk. A new species of this genus (*C. muhlisi*) has recently been described by Neu (4) from the fresh-water lake Abuliond (system of the Marmora Sea, Turkey). This species is undoubtedly identical with *C. abrau*, being evidently a subspecies of it (*C. abrau muhlisi*). No precise data as to the characters which would permit to discriminate between the species of *Clupeonella* are yet available.

A clue for determining them may be found in the table below. It is based on the examination of a considerable number of specimens.

1(2). Pectoral rounded at the end. Head large and narrow, interorbital space no more than 0.155 of head length. Caspian Sea... *C. grimmi* Kessler.

2(1). Pectoral acute, head shorter and broader, interorbital space no less than 0.16 of head length.

3(4). Body rounded, low, belly rounded, ventral scutes slightly developed. Caspian Sea..... *C. engrauliformis* (Borodin).

4(3). Body and especially belly compressed from sides, belly sharply edged, ventral scutes well developed.

5(6). Head narrow, interorbital space no more than 0.175 of head length. Abrau and Abuliond lakes... *C. abrau* (Maljatskij).

6(5). Head broader, interorbital space no less than 0.175 of head length. Black, Azov and Caspian Seas ..... *C. delicatula* (Nordmann).

The taxonomic relation between *C. delicatula* of the Caspian Sea and that of the Black and Azov Seas has not yet been ascertained. The aim of this paper is to throw a light on the subject.

A comparative study of *C. delicatula* from the Caspian and the Black and Azov Seas has shown them to differ distinctly as to the number of gill rakers, length of pectoral and ventral fins, length of head, depth of body and head, and some other characters. *C. delicatula* from the Caspian Sea and that from

the Black and Azov Seas should therefore be considered as two separate subspecies. The description of these subspecies is given below.

Clupeonella delicatula delicatula (Nordmann)

Clupea delicatula Nordmann. Faune pontique, III, 1840, p. 524 (Odessa.-market).—*Clupea cultriventris* Nordmann, l. c., p. 522 (northern coast of the Black Sea)

D III—IV 11—13 (12.0), A III 14—18 (15.4), sp. br. 49—62 (54.0), ventral scutes 24—29 (27 .0). Body and especially belly strongly compressed from sides, belly sharply edged, ventral scutes well developed. Head elongated, length 0.224—0.250 (0.237) of body length*. Pectoral and ventral fins long, pectoral 0.177—0.212 (0.19) of body length, ventral 0.117—0.138 (0.127) of same. Body and head deep, depth of body 0.213—0.27 (0.244), depth of caudal peduncle 0.076—0.093 (0.081), depth of head at the nape 0.165—0.196 (0.179) of body length. Length up to 90 mm, mostly (in the Azov Sea) 40—70 mm.

The Azov Sea and brackish parts of the Black Sea, mostly in its north-western part, Palaeostom lake, coasts of Rumania and Bulgaria, enters the mouths almost of all rivers sometimes ascending far upstream.

The description of *C. cultriventris* reminds of *C. delicatula caspia* m. *tscharchalensis*. According to Berg's (2) comparison of the mean values of some characters from the data of Antipa (1) and Brauner (3) it differs from *C. delicatula delicatula* by a somewhat deeper body. After the description of Antipa and Brauner, the profile of the back in *C. cultriventris*, as in *C. delicatula caspia* m. *tscharchalensis*, is straighter than in *C. delicatula delicatula*, in which it is somewhat curved, the belly more convex, the body deeper. Nearly all the records of *C. cultriventris* are restricted to fresh waters. In rivers, *e. g.* in the Danube, it enters in the lower parts of the mouth. *C. delicatula delicatula* ascends considerably farther upstream, in the Danube, *e. g.*, up to Brailov. A detailed comparison between *C. cultriventris* and *C. delicatula delicatula* has recently been given by Pietschmann (5) who did not found any essential differences between them. *C. cultriventris* is evidently a separate biological form (morpha), like *C. delicatula delicatula* m. *tscharchalensis*, but it differs considerably less from *C. delicatula delicatula* than *C. delicatula caspia* m. *tscharchalensis* from *C. delicatula caspia*.

Clupeonella delicatula caspia, sbsp. nova

D III—IV 11—13 (11.9), A III 14—18 (16.2), sp. br. 51—62 (56.6), ventral scutes 26—30 (27.9). Head shorter, 0.209—0.242 (0.225) of body length. Pectoral and ventral fins shorter, pectoral 0.156—0.187 (0.169) of body length, ventral 0.086—0.105 (0.095) of same. Body and head less deep, depth of body 0.18—0.242 (0.206), depth of caudal peduncle 0.056—0.078 (0.07), depth of head at the nape 0.148—0.174 (0.16) of body length. Length up to 140 mm, mostly 80—100 mm.

The Caspian Sea, where it is met with almost everywhere, from very saline parts (Kaydak bay) to quite fresh. Enters the mouths of the Volga and the Ural rivers, ascending sometimes very far upstream.

In fresh water (Tcharkhal lake in the system of the Ural River, bays of the Volga, lagoons of its delta) forms a special variety (morpha *tscharchalensis*) differing from the initial form by a less curved, straight or almost straight profile of the back, by a deeper body and some other characters.

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* The length of the body is understood throughout the paper as the distance from the tip of the snout (lower jaw) to the fork of the tail.

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ZOOLOGY

ON THE TAXONOMIC POSITION OF *CAPRA FALCONERI* WAG. IN THE USSR

By V. ZALKIN

(Communicated by I. I. Schmalhausen, Member of the Academy, 20.IV.1944)

Capra falconeri Wag., or the markhores which inhabit the most remote and inaccessible regions of Central Asia, belong to the number of rather poorly investigated species. Their area of distribution extends from the Western Himalaya and Kashmir, through Astor Ghilghit, Tibet and Afganistan, up to South Tadjikistan and Turkmenia.

Thus, but a small northern part of the total area of distribution of this species falls within the territory of the USSR.

Scarcely any reliable data as to the distribution of markhores in this country are available; it is therefore practically impossible to trace precisely the boundaries of their area of distribution. According to informations by Trubetzkoy ([2]) and Flerov ([3]), they inhabit the mountains stretching along the middle reaches of the river Piandj up to Darvaz, in the east, and Kuliab, in the west. No data as to the occurrence of markhores to the east of Darvaz are available; it is known, however, that they do not occur at the Pamir; neither have they been reported to the west of Kuliab, in the region of Shirabad. The westernmost limit of their distribution, Kughitang, is now totally isolated from the whole area of distribution. In the region of Baldjuan they are encountered, though in small numbers. Kashkarov ([1]) has reported them for Garma. Their distribution does not seem to extend so far as to the Ghissar mountains, however.

The taxonomic relations between the markhores that occur in the USSR and those of India and Afganistan have not been subjected to any serious investigation. Trubetzkoy who observed the markhores in East Bokhara points to the fact that the shape of their horns varies within a very wide range. According to this writer, separate individuals scarcely differ as to the structure of their horns from the Astor markhores (*Capra falconeri falconeri*) and the Suleyman markhores (*C. falconeri jerdoni*), or from the rest of races of this species that occupy a taxonomic position intermediate between the two extreme types mentioned above. The opinion of Trubetzkoy has subsequently been almost literally confirmed by Flerov. The latter believed the variation in the horn structure of *Capra falconeri* to be of individual rather than geographical nature; this made him conclude as to a total inconsistency of the modern subspecific taxonomy of this species, and to a necessity of its radical revision.

We examined in detail the whole collection of markhore horns that had been gathered by Trubetzkoy in East Bokhara and served as material for his conclusions. We also thoroughly investigated the collections made by Roegel and Alexeyev which, along with Trubetzkoy's collection, made Flerov to arrive at his rather uncompromising conclusion. Thus, we were able to get acquainted with the bulk of material which was at the disposal of the authors listed above.

Being not satisfied with this, we have investigated a fine series of markhores that have been collected within the recent years by the Zoological Museum of the Moscow University, and also a series of 18 animals killed in the Dashtidjum region of Tadjikistan, and at the Kughitang. We have likewise examined a few small collections and separate specimens belonging to some other institutions (the Turkmenian Branch of the Academy of Sciences of the USSR, the Turkmenian Museum at Ashkhabad, *etc.*), which makes up a total of 60 individuals of this species.

Thus, we disposed of a much more extensive material than either of the authors cited above. Naturally enough, this enabled us to form a more accurate

Fig. 1. 1 : 12

Fig. 2. 1 : 12

judgment as to the nature and range of variation of the structure of the horns of markhores*. However, we failed to derive from the material investigated anything that would substantiate the opinion expressed by Trubetzkoy and Flerov, our own conclusions being entirely at variance with it.

We do not see in the structure of the horns of the Tadjik markhores the high degree of individual variation expressed in the shape of the coils of the spiral formed by heteronymously winding horn trunks, as is claimed by the two earlier writers.

On the contrary, the horns of the animals described seem to be rather uniform in this respect. Important individual deviations may be recorded in the width to which the tops of the horns are set apart, or in the way they are fixed to the skull, but both these characters are of secondary importance for the racial differentiation of the markhores. The most important character to be taken into account is the shape of the coil, which has already been pointed out by Liddeker and others.

In a vast majority of cases the markhores of Tadjikistan show the same rather stable type of a narrow and tight coil (Fig. 1).

The Kughitang markhores which differ from the Tadjikistan markhores by a wider and gentler coil, show also a considerable monotony in its shape and size; the width between their horn tops and the setting of the latter upon the skull are subject to important individual variations (Fig. 2).

The coil types inherent on the markhores of the two regions are so characteristic that they can readily be differentiated according to this character.

At the same time we can safely maintain that among the total material studied by us there was not a single specimen of horns that might be considered

* The scope of the present note prevents us from dwelling upon the description of the exterior and craniological peculiarities of the markhores. The only character we shall be concerned with is the structure of the horns, which is of paramount importance in subspecific taxonomy of the markhores.

identical with, or even merely similar to those of the markhores from Astor or from the Suleyman mountains. The description made by Trubetzkoy and Flerov is so far from corresponding to what is actually being observed, that we cannot term it otherwise than a most disappointing error.

The horns of the Tadjik and Turkmenian markhore can be rather easily distinguished even from those of the remaining races, whose structure occupies an intermediate position between the two extreme types referred to above (the Astor and Suleyman markhores). The most closely related to the Tadjikistan markhores as to the shape of their horns is the Ghilghit markhore (*Capra falconeri* subsp.?) whose horns are, however, much heavier and have a less steep coil of the spiral. In the Kughitang markhores this character brings them near to the Kabul markhores (*C. falconeri megaceros*). These, however, are characterized by rather straight horns which somewhat approach the spiral-like type. This is not observed in the Kughitang markhores whose horns have a clearly expressed corkscrew pattern.

The area of distribution of the Tadjikistan and Turkmenian markhores seems to be rather well isolated geographically from that of the rest of races. From the Indian races they are divided by the vast Pamir upland; from the Afganian, by the rivers Piandj and Amu-Darja; the latter may well be supposed to have served as a barrier and geographical boundary, especially for such a purely mountainous form as the markhore.

The monotony in the types of horns, along with an important divergence of their shape from that of other races, and a sufficiently delimited area of distribution, make us regard the markhores from Tadjikistan, on the one hand, and those from Turkmenia, on the other, as being different races of the species *Capra falconeri*.

For the race that occurs in Tadjikistan, inhabiting there the mountains along the right-hand bank of the Piandj River, we suggest the name of *Capra falconeri heptneri*.

Type: Horns No. S-34824 from the Zoological Museum of the Moscow University. ♂, 10 years old. Dashtidjum region of the Tadjik SSR, 1937, collected by D. P. Dementiev (Fig. 1).

Paratypes: Cranium with horns No. S-38535 of the Zoological Museum of the Moscow University. ♂, 5 years old. Dashtidjum region of the Tadjik SSR, summer 1937, collected by D. P. Dementiev. Horns No. 12531, Zool. Inst. Acad. Sci. USSR, East Bokhara, Kuliab, 1909, collected by P. S. Trubetzkoy. Horns No. 12528, Zool. Inst. Acad. Sci. USSR. ♂, 7 years old, ibidem, idem. Horns No. 12534, Zool. Inst. Acad. Sci. USSR. ♂, 9 years old, ibidem, collected by Alexeyev. Horns No. 12529. Zool. Inst. Acad. Sci. USSR. ♂, 5 years old, ibidem, collected by P. S. Trubetzkoy. Horns No. 12530, Zool. Inst. Acad. Sci. USSR. ♂, 7 years old, ibidem, idem. Horns No. 12527, Zool. Inst. Acad. Sci. USSR. ♂, 6 years old, ibidem, idem.

Diagnosis: *Capra falconeri heptneri*, characterized by heavy thick horns with tight and relatively narrow, corkscrew-like coils of the spiral; in adults number of coils may exceed two. The relation between the length of the horns measured along the straight line, to that measured along the coils varies from 0.76 to 0.85. The distance between the tops of the horns and their setting upon the cranium are subject to considerable variations.

Area of distribution: Mountains of East Tadjikistan, approaching the right-hand bank of the River Piandj.

For the race inhabiting Kughitang we suggest the name of *Capra falconeri ognevi*.

Type: Skull with horns No. S-38919, Zool. Museum of the Moscow University. ♂, 7 years old, Kughitang, Karluk region of the Turkmenian SSR, 1941 (Fig. 2).

Paratypes: Horns No. S-34826, Zool. Museum of the Moscow University. ♂, 4 years old, Kughitang (forest Ir-Don), Karluk region of the Turkmenian SSR, II. V. 1936, collected by V. B. Grinberg. Skull with horns No. S-38906, Zool. Museum of the Moscow University. ♂, 4 years old, Ku-

ghitang, Turkmenian SSR. Skull with horns No. S-34825, Zool. Museum of the Moscow University. ♂, 3 years old, Kughitang (forest Ir-Don), Karluk region of Turkmenian SSR, II. V. 1936, collected by V. B. Grinberg.

Diagnosis: Differs from the race previously described by having broader and more gently sloping coils (not spiral-like); in adult specimens their number reaches two. Relation between the length of the horn measured along the straight line and along the coils varies from 0.85 and 0.93. Distance between the tops of the horns and their setting upon the skull subject to important variations.

Area of distribution: Kughitang.

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EXPERIMENTAL MORPHOLOGY

RELATION BETWEEN EPITHELIUM AND CONNECTIVE TISSUE IN THE CASE OF REGENERATION OF SKIN OVERLYING A FOCUS OF INFLAMMATION

By A. A. BRAUN

(Communicated by A. A. Zavarzin, Member of the Academy, 29.IV.1944)

Both in vertebrates and invertebrates intimate relations have been found to exist between the epithelium and the underlying connective tissue ([1–5]). These system interrelations are observed with special clearness in the process of regeneration, or when epithelization of a foreign body inserted into the internal medium of the organism takes place. The epithelial layer overgrows the young connective tissue, and in the latter case it penetrates between the connective tissue and the necrotic zone which is formed around the foreign body. If in the connective tissue just under the epithelium an inflammatory process takes place, leading to the destruction of the basal membrane, the epithelium forms outgrowths into the underlying substratum, *i. e.* displays a phenomenon which, after Garshin, is called an infiltrative epithelial growth. The authors above-cited have shown the biological rôle played by the outgrowths in question, resulting in the elimination of a foreign body from the internal medium of the organism. However, the actual cause of the formation of those outgrowths was not yet clear, being the subject of some difference in opinion ([2–4]).

Having studied the interrelation between epithelium and connective tissue in the regeneration process of the skin overlying an inflammatory focus in amphibiae, I found the epithelial growth towards the inflammatory focus to be an active and directed one, and to be due to the chemotactic stimulation on the part of the focus of inflammation. The directed growth of epithelium towards the inflammatory focus should be considered as having a great biological value, and as a factor contributing to the eliminative function of the epithelium.

The experiments here described were carried out on frogs. The presence of a subcutaneous lymphatic sack in this animal facilitates experimentation, involving the insertion and fixation of a foreign body in a definite place. In order to induce aseptic inflammation, small pieces of cellulose cinema-film with or without a gelatinous layer were introduced into the subcutaneous lymphatic sack in the dorsal or head region. The material was fixed with Zenker-formol solution and embedded into paraffin. Sections were stained with haematoxylin-eosin or, in a number of cases, after Mallori, and silvered after Belshovsky-Maresh. A total of 200 experiments were carried out which fall into three principal series.

The first series comprises experiments arranged in the following way: a piece of cinema-film was introduced into the subcutaneous sack. Later on (after 0 to 20 days) there was excised a piece of skin over the implanted film throughout its thickness. The regenerate was fixed 1—9 days later.

When a frog skin is injured, the connective tissue defect is soon filled with a fibrin coagulum, the edges of which are soon covered with the growing epithelium.

The epithelial regenerate does not form any outgrowth into the underlying substratum under the usual conditions of regeneration.

In my experiments the defect in the connective tissue of the skin was also filled by fibrin. Like in the experiments described above, the latter was soon covered with an epithelial layer. However, at early stages of the inflammatory process, when an afflux of floating elements has just been formed around the foreign body, the epithelial regenerate is already found to contain small outgrowths. These outgrowths are, as a rule, pointed in shape, which points to the active character of their movement. The ingrowth of the epithelium into fibrin is not connected with cell proliferation. It is observed before the formation of mitotic figures, and is to be considered as a result of an active movement of the epithelial cells.

The outgrowths are basophilous and of cellular nature. The large outgrowths sometimes look like protrusions of the epithelial layer in which the continuation of the basal layer and of the overlying ones may be traced over a considerable distance. The outgrowths increase in size, and move towards the foreign body. Along with this active movement of the cell material, cell proliferation also participates in the formation of outgrowths and their subsequent increase. Mitotic figures are observed in the outgrowths themselves, as well as in the whole epithelial regenerate. There are often observed also amitotic cell divisions, giving rise to binucleate, trinucleate and even polynucleate cells. When the outgrowths reach the foreign body, epithelization of the latter sets in, this process being often followed by the fusion of the outgrowth with one another. All these processes usually take place under the covering epithelial regenerate. Then in the central part of separate outgrowths a gradual process of carotinization of the cell elements begins, along their longitudinal axes, resulting in a complete break in the epithelial outgrowth. Epithelization leads to a complete overgrowing of the foreign body, while the break in the outgrowths prepares the way for its elimination.

According as the inflammatory process becomes less intense, the outgrowth formation in the epithelial regenerate decreases; and if a bit of skin over inserted cinema-film was allowed to stay in a lymphatic sack for about 20 days, and is overgrown with a connective tissue capsule, the regeneration process goes on in the same way as under normal conditions. The absence of outgrowths and the normal aspect of the epithelial regenerate formed over the incapsulated foreign body are evidence against a direct action of the latter upon the epithelium.

Thus, the first series of experiments has already shown: (1) the ingrowth of epithelium into the underlying substratum is the responsive reaction of the epithelium to a stimulation proceeding from the inflammatory focus; (2) the factor responsible for those stimuli is not the foreign body itself, but some influences arising in the inflammatory focus at an early stage of inflammation*. The latter conclusion gives every reason to suppose that (3) these stimuli arise within the zone of necrosis that is formed in the immediate neighbourhood of the foreign body.

As soon as the processes that take place around the foreign body pass from the destructive phase into the regenerative one, morphologically characterized by the formation of a fibrous capsule, the formation of epithelial outgrowths comes to a stop.

In the second series of experiments the excision of a fragment of skin was followed by the insertion of a piece of cinema-film under the regene-

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* In his recent investigations on the influence of extracts from inflammation foci in tissue cultures Lazarenko has independently arrived at similar conclusions. He was able to show that at an early stage of inflammation some substances are formed in the inflammatory focus which stimulate the growth of different tissues.

rate; the age of the latter varied from 3 to 7 days. Thus, in different experiments we had different substrata between the epithelial regenerate and the inflammatory focus.

The experiments with early regenerates where the underepithelial fibrin coagulum did not yet contain any fibroblasts, have revealed relations similar to those of the first series of experiments. It is interesting to note that in those cases where the area of the wound exceeded considerably the width of the cinema-film stripe and the latter was introduced under one of the edges of epithelial regenerate, the first epithelial outgrowths arised just over the place where the foreign body was seated.

In the experiments with late regenerates a rather thick fibroblast layer is

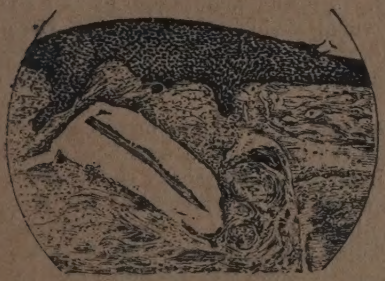

Fig. 1. Photomicro, 1×50 (Zenker-formol, haemotoxylin-eosin). Frog skin. Cinema-film stripe introduced under a 5-day-old regenerate. Fixation after 3 days upon insertion. Outgrowths formed over implanted stripe and moved towards it

Fig. 2. Photomicro. Magnification and treatment same as in Fig. 1. Frog skin. Cinema-film stripe implanted under a 9-day-old regenerate (rather thick layer of fibroblasts present under epithelium). Fixation after 5 days upon implantation. Young connective tissue present in regenerate under epithelium. Epithelium does not form any outgrowths, but reacts to the foreign body by a strong thickening

present under the epithelium. In these cases the epithelium does not form any outgrowths into the underlying substratum. However, it sharply reacts to the inflammatory process taking place under the epithelium. Morphologically this process is expressed in a very strong thickening of epithelium over the inflammatory focus.

This phenomenon which Garshin was the first to describe for mammalia and man under the name of «non-dipped growth», is accounted for by the influence of the inflammatory focus upon the epithelium. Peculiar to such epithelial thickenings is the increase in the size of their cells and the presence of binucleate, trinucleate, and sometimes even gigantic cells arising in large numbers by way of amitotic division.

In these cases the incapsulation of the foreign body is the final result of its isolation from the internal medium of the organism. The epithelium gradually comes to a stillstand and assumes its normal appearance.

Thus, the experiments of this series have also shown: (1) the inflammatory focus is the source of certain agents that stimulate the epithelium, and (2) the movement of epithelial outgrowths formed under the influence of these agents is not only on active one, but is also directed towards the stimulating action of the inflammatory focus.

In the third series of experiments the fragments of the cinema-film were implanted under the skin of the frog. Somewhat later (from 0 to 7 days) the epidermis and the spongious layer including glandulae were stripped of the skin over the implanted film. In the naked region of the compact layer of the

derm a hole was additionally made with the help of a dissecting needle. The regenerates were fixed at various intervals, according to the case.

The examination of the material showed that the defect in the spongious layer of the derm is filled with fibrin coagulum just in the same way as in the case of deeper wounds. The epithelium overgrows the fibrin in the marginal zone, and within one—two days the wound area is found to be completely epithelized. Then outgrowths stretching into the fibrin appear in the epithelial regenerate. The first epithelial outgrowths are formed just over the hole made in the compact derm layer. Gradually increasing in size these outgrowths move within the fibrin towards the canal in the compact layer, pass through it, and then begin in the usual way to epithelize the foreign body lying in the lymphatic sack.

Thus, the three series of experiments here described permit of the following conclusion.

In the inflammatory focus (apparently, in its necrotic zone) at an early stage of inflammation some substances are formed which stimulate the epithelium, inducing a growth directed towards the inflammatory focus and the chemotactic stimuli. If their directed growth is prevented, a vigorous growth of epithelium at its initial place takes place.

It has also been shown that the elimination of a foreign body or its isolation in the internal medium of the organism is realized in two ways: (1) with the aid of the elements of the internal medium itself, *i. e.* by means of incapsulation of the foreign body with a subsequent formation of an epithelioid boundary layer surrounding it; (2) with the aid of epithelium. The latter process takes place in cases where the epithelium reaches a foreign body before the destructive processes and the formation of a fibrous capsule around the foreign body are achieved. In these cases the foreign body is epithelized and then eliminated from the organism.

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